SILVER BOW CREEK INVESTIGATION

STARS - PHASE II

PILOT SCALE TREATABILITY STUDY

WORK PLAN

PLEASE RETURN

CH2M HILL

STARS - PHASE II

PILOT SCALE TREATABILITY STUDY

WORK PLAN

STREAMBANK TAILINGS AND

REVEGETATION STUDY

FIELD PLOT CONSTRUCTION AND VEGETATION SEEDING

submitted by:

Schafer and Associates
Bozeman, MT

CH2M Hill
Helena, MT

Reclamation Research Unit
Montana State University

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Scott Brown/USEPA, SMO, Helena

Deanna Peterson/USEPA, VIII, RSCC, Denver, Colorado

Mike Rubich/MDHES, Helena

Kathy DeMarinis/MDHES, Helena

Dave Bunte/CH2M HILL, Helena

Lynn Riddick/SMO, Alexandria, Virginia

Bill Schafer/Schafer and Associates, Bozeman

Dennis Neuman/MSU, Bozeman

CONTACT INFORMATION

CONTACT INFORMATION

Case Coordinator:	Lynn Riddick USEPA, CLP, SMO 300 North Lee Street PO Box 818 Alexandria, Virginia 22313 (703) 557-2490
Region VIII CLP Coordinator:	Deanna Peterson USEPA, VIII, RSCC Denver Federal Center Building 53, P.O. Box 25366 Denver, Colorado 80225 (303) 236-7370
Remedial Project Manager:	Scott Brown USEPA, SMO Federal Building, Room 292 301 South Park Avenue Drawer 10096 Helena, Montana 59626 (406) 449-5486

CONTACT INFORMATION (continued)

State of Montana Project Manager:	Kathy DeMarinis Solid Waste Management Bureau Montana Department of Health and Environmental Sciences Room B-201, Cogswell Building Helena, Montana 59620 (406) 444-2835
Site Project Manager:	Dave Bunte CH2M HILL 1610 B Street Helena, Montana 59601 (406) 442-4116
Subcontractor Site Project Manager:	William Schafer Schafer and Associates P.O. Box 6186 Bozeman, Montana 59715 (406) 587-3478
Subcontractor Site Project Manager:	Dennis Neuman Reclamation Research Unit Montana State University Bozeman, Montana 59717 (406) 994-4821

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PREFACE

This document describes the field activities for investigating innovative measures to modify streambank tailings (mine wastes), located along Silver Bow Creek, sufficiently to allow them to be revegetation. This document has been prepared using EPA guidance for pilot-scale treatability testing and conforms to the suggested format for pilot-scale work plans (EPA, 1988).

This document is closely related to other project documents, and they have been cited in this document. For additional information and technical detail the following documents may be helpful to gain an in-depth understanding of the Streambank Tailings and Revegetation Studies (STARS) project:

o MSU and Schafer & Associates, 1988. STARS Transition Phase Technical Memorandum for the Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS: Methods for Conducting Field Site Selection and Sampling of Phase II Plots. June 10, 1988.

o MSU and Schafer & Associates, 1987a. Quality Assurance Project Plan (QAPP) for the Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS. Submitted to EPA Region VIII. Doc.No. SBC-STARS-QAPP-F-RO-121187.

o MSU and Schafer & Associates, 1987b. Laboratory Analytical Protocol (LAP) for the Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS. Submitted to EPA Region VIII. Doc. No. SBC-STARS-LAP-F-RI-121187.

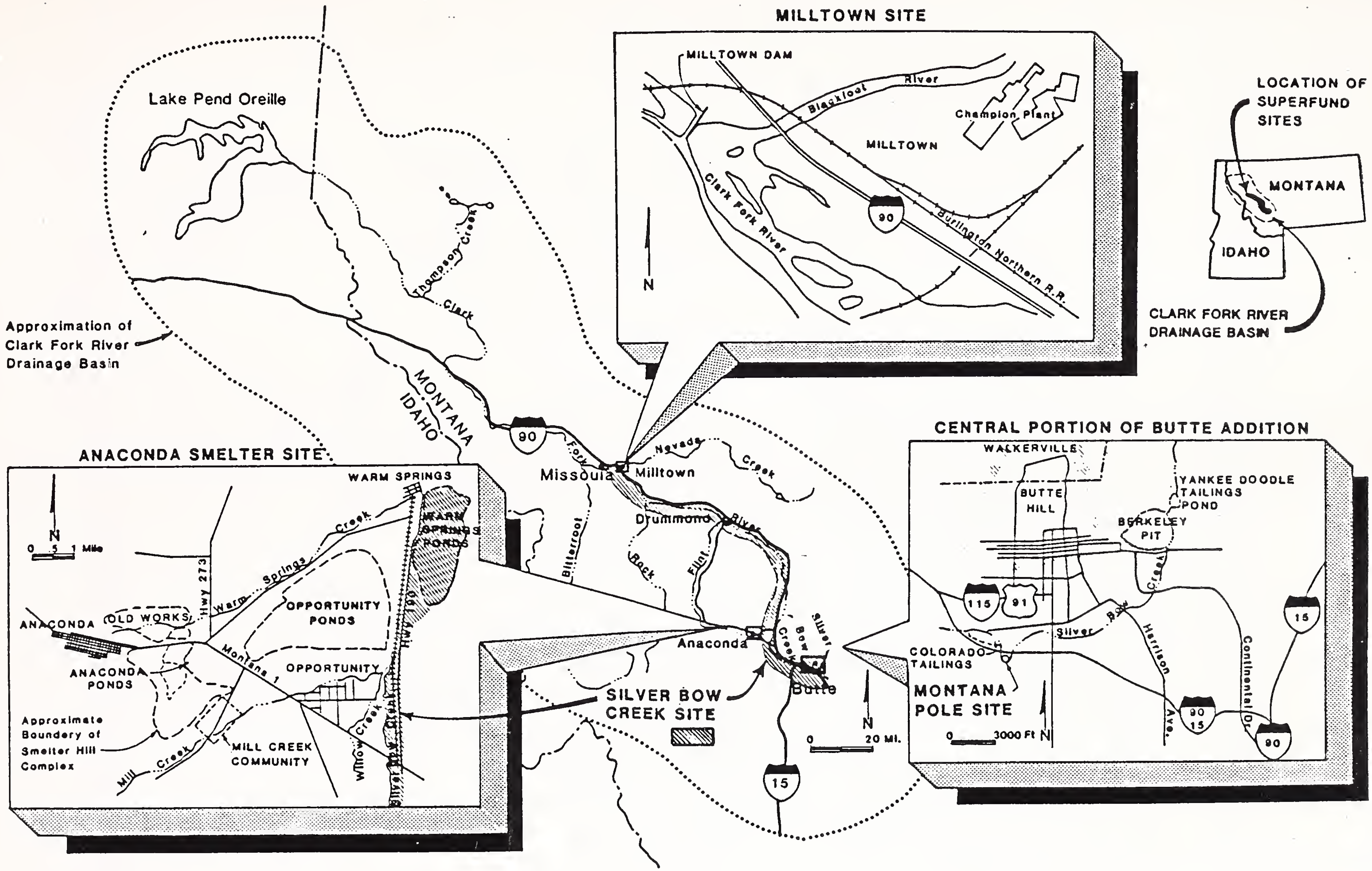
1.0 PROJECT DESCRIPTION

1.1 Site History

The upper Clark Fork River basin has been a center of mining activity since the 1860's. Contamination of land and water by mining waste is widespread because of the extensive mineral processing activities which have occurred. Due to the complexity of the mine waste contamination, several Superfund sites have been formed in the Clark Fork River basin. The Silver Bow Creek site, the largest designated Superfund site in the U.S., extends from the uptown portion of Butte, Montana downstream to the Milltown Reservoir near Missoula, Montana (Figure 1.1). The upper portion of the Silver Bow Creek site known as the Butte addition is administered by the EPA with the Atlantic Richfield Company (ARCO) designated as a potentially responsible party (PRP). For the lower part of the Silver Bow site known as the Clark Fork River site an assessment is being conducted. The remainder of the Silver Bow site from Butte to the Warm Springs treatment Ponds (a State-lead site) is the subject of this investigation. Other Superfund sites in the area include the Montana Pole site, the Anaconda Smelter site, and the Mill Town Reservoir site. Montana Pole, also located in Butte, is a historic pole treating site with PCP contamination. The Anaconda Smelter site is centered at Anaconda, Montana 22 miles downstream of Butte. Most Butte ores were processed in Anaconda after 1904. The Milltown Reservoir site located near Missoula consists of several million yards of mine waste deposits in the reservoir which have liberated arsenic and metals into ground water.

1.2 Description of the Silver Bow site

The Silver Bow Creek CERCLA Study Area is an extensive inorganic contamination site, located between Butte, Montana and the Warm Springs treatment ponds near Warm Springs, Montana. Contamination of the Silver Bow Creek drainage consists primarily of heavy metals (lead, cadmium, copper, manganese and zinc), arsenic, and acid-producing sulfides which pose



SUPERFUND SITES IN THE CLARK FORK RIVER BASIN

Figure 1.1 Location of Superfund sites in the upper Clark Fork River.

potentially major health and environmental hazards. Typical levels of metals in mine wastes situated along Silver Bow Creek are shown in Table 1.1.

Contamination of air, soil, surface and ground water is derived primarily from tailings and other mining waste deposited in the Silver Bow Creek channel and floodplain. Several million yards of mining waste are found in the floodplain of Silver Bow Creek. Remediation of these wastes is the focus of RI/FS activities on the Streambank Tailings operable unit of the Silver Bow Creek investigation. Streambank tailings are situated so that they are eroded by wind or water. Sulfide oxidation in the mine wastes increases acidity which in turn causes most metals to be more mobile. As water percolates through or flows across the barren streambank mine wastes, metals are leached into surface and ground water.

Table 1.1. Typical concentrations of contaminants in mine wastes situated along Silver Bow Creek.*

PARAMETER	ARITHMETIC MEAN	MAXIMUM VALUE
pH	3.97	2.30 (lowest)
EC (mmhos/cm)	3.44	7.70
Sand (%)	62.2	90.0
Silt (%)	25.7	68.1
Clay (%)	12.1	30.4
	GEOMETRIC MEAN	MAXIMUM VALUE
	(mg/kg soil)	(mg/kg soil)
Copper	1,410.	11,200.
Zinc	2,140.	22,000.
Lead	912.	6,477.
Cadmium	11.2	108.
Arsenic	347.	3,140.
Manganese	977.	13,300.
Chromium	10.7	142.
Mercury	5.0	61.

* Data are taken from initial characterization of 35 bulk mine waste samples collected for STARS, Phase I.

2.0 REMEDIAL TECHNOLOGY DESCRIPTION

2.1 General Remedial Response Objectives

Remedial measures for streambank tailings must solve a variety of problems. These include acid production and movement of contaminated leachate to surface and ground water, erosion by water and by wind and direct contact hazard to humans and livestock or wildlife. Typical remedial alternatives which may correct most of these problems include removal to a secure storage area or capping to reduce precipitation infiltration and air entrainment. These techniques work well for sites with small areal involvement or volumes; however, for sites in which the areal extent of contamination is very large and involves large volumes of material the practical application of these technologies decrease significantly. Since streambank tailings along Silver Bow Creek are disseminated over much of its 27 mile length, and involve millions of cubic yards of material the Montana Department of Health and Environmental Sciences (MDHES) agreed that new and innovative technologies should be investigated as remedial alternatives. One of these technologies is modification of tailings characteristics (pH, plant-available metals) followed by revegetation.

2.2 Remedial Alternative Description

A cost-effective in-situ remedy for steambank wastes is needed to mitigate the adverse effects of the extensive mine wastes along Silver Bow Creek. An innovative remedial measure conceptualized by the project team involved 1) chemical neutralization and fixation of contaminants through deep-incorporation of soil amendments into mine waste, 2) possible use of a soil cap (at least in selected areas), and 3) revegetation with acid or metal-tolerant species of grasses. Soil amendments would reduce the mobility and toxicity of contaminants while the soil cap (if used) and vegetation cover would reduce the quantity of leachate through waste materials.

2.3 Purpose and Scope of the STARS Pilot Study

The Streambank Tailings and Revegetation Study (STARS) was initiated to develop an innovative remedial technique and to investigate the effectiveness of that technique. The STARS project was divided into a laboratory/greenhouse (phase I) component to develop and test treatments at a bench scale, to be followed by a field scale (phase II) demonstration of selected remedial alternatives.

The purpose of Phase I of STARS was to develop and test innovative remedial measures to modify streambank tailings (waste) characteristics sufficiently to allow them to be revegetated. Phase I of STARS is on-going. Chemical amendments were added to selected waste material in column studies to determine if the leaching of metals to ground water and the contamination of runoff could be abated. At the completion of the column investigation, greenhouse tests were implemented to select species that can be used to revegetate amended wastes. The objectives of the revegetation program are to reduce fugitive dust, reduce leachate to ground water due to enhanced evapotranspiration, and to provide surface soil protection.

Phase II activities will include field implementation of the remedial options designed in Phase I and evaluation of the response of the treatments in reducing leachate quantity and in abatement of metal flux to surface and ground water. The overall project schedule was designed to allow siting, and construction of demonstration plots so that fall-seeding can be performed on the plots in 1988. Because Phase I STARS is still on-going, specific treatments for the field plots have not yet been finalized. As a result, the conceptual field plot treatments designed in this work plan will be generic and will be replaced by specific treatments at the completion of the Phase I greenhouse studies. Interim activities required to ensure the timely completion of the STARS investigation have been initiated under the guidance of a Technical Memorandum. The purpose of the interim activities (Transition Phase - STARS) is to identify and select candidate locations for installation of the STARS field plots, to identify homogeneous plot locations and to measure selected soil and site parameters needed for remedial design. Although these activities are already proceeding, they are included in this

work plan (tasks 1 through 4) for completeness.

This work plan has been assembled to describe field activities anticipated under Phase II of STARS including the special equipment and services required, the technical approach to be used for field plot implementation, the design of the field experiment, and the kinds and number of analytical determinations.

Six waste samples were collected for column and greenhouse studies which were representative of the kinds of contaminated materials found on-site. Five sites corresponding to five of the six waste sample locations have been selected for field plot implementation. One candidate site, the buried soil site, will not be included in the phase 2 STARS investigation. The sites to be evaluated are thought to be representative of the variety of waste materials found on-site (Table 2.1 Figure 2.1). Three types of tailings are found in streambank tailings deposits. These waste types, delineated using statistical methods, differ in basic soil physical and chemical properties. Type 1 tailings are sandy, low in rock fragments, and have pH and EC values intermediate to the other tailings types. Type 2 tailings consist of coarse sand and gravel, have low pH (3 to 3.5) and low EC (<1.5 mmhos/cm). Type 3 tailings are silty, have higher pH than other tailings (pH>4) and have high EC (>4 mmhos/cm). Many upland soils affected by infrequent flooding (through irrigation systems) have been contaminated sufficiently to reduce or eliminate plant growth. Materials from tailings impoundments were also investigated because their properties may differ from streambank wastes deposited in the Silver Bow Creek floodplain.

A sample representative of natural soils buried by wastes was also selected for phase 1 column and greenhouse studies because removal of waste from along the streambank to facilitate channel stabilization may require the remediation of buried soils in selected locations. The buried soil site will not be implemented in phase II, however. It was felt that 1) where tailings were selectively removed for stream stabilization that contaminated soil layers would also be removed, and 2) the cost and effectiveness of a STARS remedy for buried soils could be inferred from results on other sites, especially the flooded soil site.

The sampling described in this work plan includes only plot construction and seeding of field plots. The purpose of the sampling effort in support of plot construction is to identify and select candidate locations for installation of the STARS field plots, to identify homogeneous plot locations and to measure selected soil and site parameters needed for remedial design. Subsequent to the completion of activities outlined in this work plan, a modification will be prepared to describe in detail the monitoring strategy for measuring the effectiveness of the remedial treatments implemented. This work plan modification will outline the timing, kinds, and numbers of samples to be collected after construction of the field plots, the kinds of field monitoring and sampling techniques to be utilized, and the specific data analysis and interpretation methods to be employed in measuring treatment response.

Table 2.1 Candidate samples investigated in Phase I STARS column and greenhouse studies.

SAMPLE NUMBER	CLASS*	SITE NUMBER	DESCRIPTION
501-1-1	1	33	Sandy tailings
556-2-1	2	7	Gravelly low pH, low EC tailings
537-1-1	3	21	Silty, moderate pH, high EC tailings
559-3-1	T	2	In-place tailings impoundment
553-1-2+	B	9	Buried soil site
513-2-1	F	27	Flood-affected soil site

* Classes include type 1-3 tailings defined in earlier reports, in-place tailings (T), buried soils (B), and flood-affected soils (F).

\+ The buried soil site will not be implemented in Phase II.

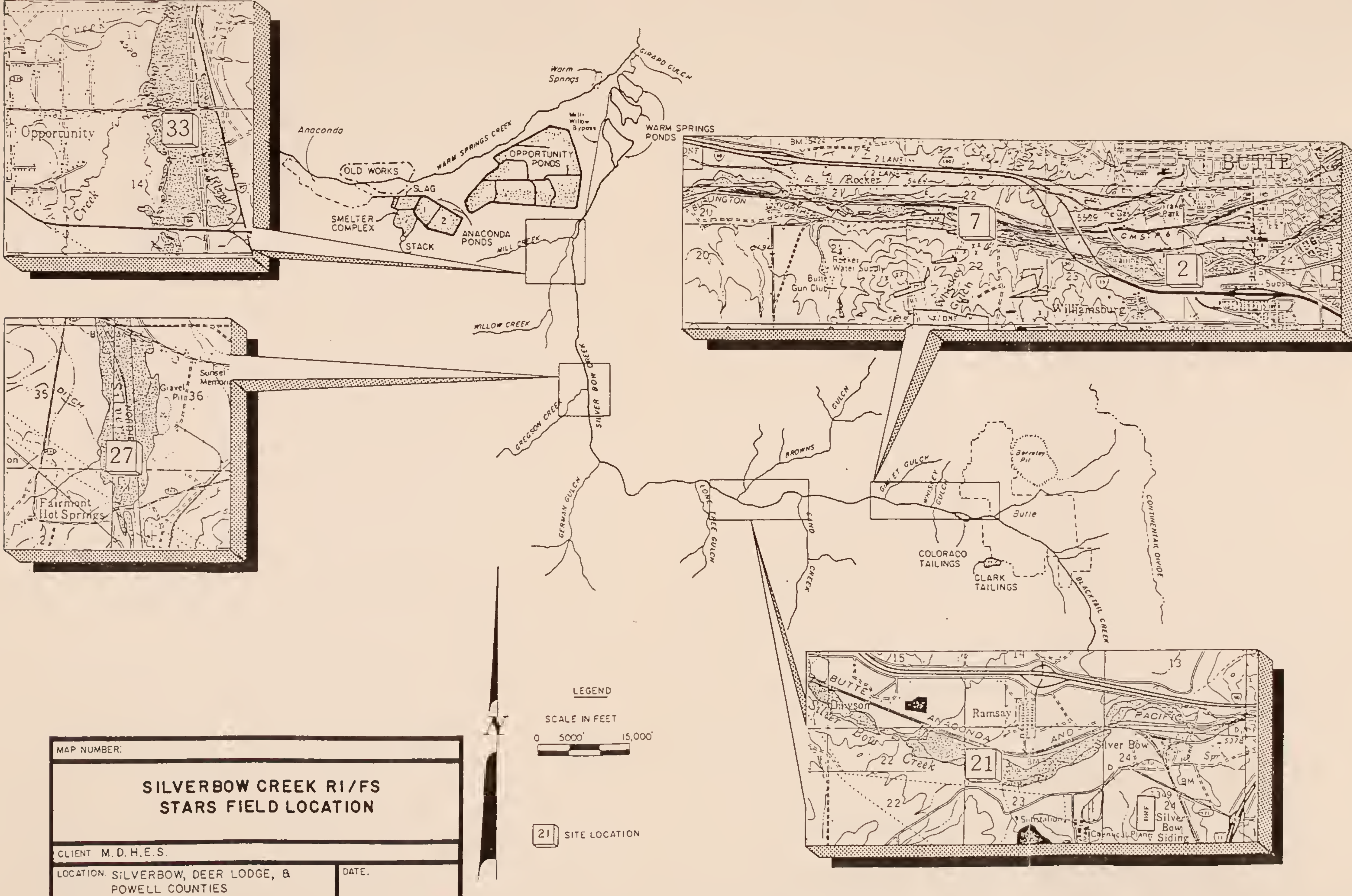


Figure 2.1 Candidate Phase II STARS field plot locations.

3.0 TEST OBJECTIVES

3.1 Overall Objectives of STARS

The primary objectives of the Streambank Tailings and Revegetation Study (STARS) are to:

GENERAL OBJECTIVE 1: Design, field test, and evaluate the response of potential remedial measures for mitigation of human health and environmental impacts from streambank tailings using chemical microencapsulation, deep incorporation, cover-soil isolation, and enhanced evapotranspiration techniques.

GENERAL OBJECTIVE 2: Develop a method of ranking tailings-contaminated areas for selecting contaminated remedial measures.

These objectives will allow the RI/FS project team to collect the required performance data to design selected innovative remedial alternatives for consideration in the feasibility study.

3.2 Objectives of STARS Phase II Field Plot Construction:

The specific objectives for Phase II of the STARS project are to:

SPECIFIC OBJECTIVE 1: Locate and delineate field plot locations for each candidate soil or tailings (waste) investigated in Phase I column and greenhouse investigations. Suitable sites will be determined to be representative of the candidate sample, relatively homogeneous, and accessible by heavy equipment.

SPECIFIC OBJECTIVE 2: Samples will be obtained from each plot at each site and will be analyzed for those parameters necessary to design field treatments. Determination of total metal levels and of plant nutrient availability is also required. Splits of samples will be archived for comprehensive analysis at a later date. These archived splits will represent unamended (baseline) chemical conditions.

SPECIFIC OBJECTIVE 3: Selected soil amendments will be incorporated into field plots at the candidate sites using agricultural tillage implements (6 inch depth of incorporation), mechanical deep-incorporation methods (18 inches), and pressure injection methods (to 20 feet or more).

SPECIFIC OBJECTIVE 4: After waiting for chemical amendments to equilibrate for a specified period, selected acid- or metal-tolerant vegetation will be seeded into the chemically-treated plots by the fall of 1988 for a dormant seeding.

4.0 PILOT STUDY INSTALLATION

The first four tasks identified in the plan have been initiated under the guidance of a Technical Memorandum (Schafer and Associates and MSU, 1988). They are included here to provide a complete outline of Phase II STARS field activities and to portray the logical sequence of field tasks to be completed. After completion of task 6 (plot seeding), a work plan amendment describing task 7 (field plot monitoring and maintenance) will be developed to describe methods to be used for measuring the effectiveness of the STARS remedial treatments.

4.1 Task 1: Assess Field Variability

The variability of the mine wastes in the vicinity of six waste samples collected in Phase I (Figure 2.1) will be characterized by measuring several parameters in a grid of sample points. At each site an area of 70,000 square feet will be selected with a grid spacing of approximately 35 feet. At each grid point several field measurements will be made of the 0-6 inch material. Samples will be collected at 6 to 18 inches and at 18 to 48 inches at 8 to 15 selected grid points to assess the vertical changes in soil properties. This screening step will ensure that field plots are both homogenous so that treatment effects are not obscured, and are representative of the bulk sample of mine waste investigated in Phase I, Column and greenhouse investigations.

Field measurements in a grid pattern will include saturated soil paste pH, EC of a 1:10 soil/solution suspension, and total metal levels measured by X-ray Fluorescence Spectroscopy (XRF). These properties will be measured using Standard Operating Procedures described in Appendix A. At each deep sampling location at each site (8 to 15 soil descriptions per site), a generalized soil profile descriptions will be developed to identify characteristics of deposits with depth, to record tailings thickness, and to measure the depth to ground water (Appendix A). All field data will be written on prepared field forms to facilitate accurate recording of data. This procedure is to ensure that proper calibration, and decontamination

procedures are followed and that other quality assurance program steps are followed. The QA/QC program objectives are contained in section 4.0. Calibration and operating procedures for all field equipment is in Appendix A.

Individual data points for the 0 to 6 inch zone will be analyzed by a block kriging program which is a statistical technique for drawing contour lines of equal concentration (isopleths) on maps of the site. This statistical program also provides an estimate of variability of measured parameters. Hence, the plots can be located in areas with levels of key parameters within known confidence limits of a particular target value. For example, if total copper of the Phase I bulk sample was 2100 mg/kg, we may choose to locate plots only on sites within the 90 percent confidence level of that value. If the 90 percent confidence level corresponded to ± 300 mg/kg copper, then plots could be placed where copper values ranged from 1800 to 2400 mg/kg copper. If the block kriging program does not provide a satisfactory model, then a traditional moving weighted average mapping technique will be be used to produce isopeth maps from the raw data.

Plot homogeneity will be determined using isopeth maps of field parameters (pH, EC, total Zn, total As) and other significant factors (waste material thickness, depth to ground water). The intent of the screening procedure conducted on the large area (70,000 square feet) is to select a smaller area which is representative of the waste material type and as homogeneous as possible, to locate the replicated study plots. It is hoped that study locations will have chemical properties within 25 percent (measured by relative percent difference) of the values for the bulk sample collected from the site. If typical chemical concentrations fall outside these control limits than a decision will be made to select plots outside the control limits or to expand or move the candidate field plot area. Blocks within each plot will be orientated to result in as little variability as possible.

Results of the site screening procedure will be displayed on a series of maps each showing the contoured values and associated variance for each measured parameter. Maps will be overlaid to find areas best-suited for locating plots. The replicated plots will cover an approximate area of 12,000 square feet.

4.2 Task 2: Design / Locate / Delineate Field Plots

Experimental soil amendment treatments, amendment incorporation techniques, and vegetative mixtures developed during the Phase I STARS investigation will be evaluated at five field plot locations. Since Phase I STARS is on-going, the specific treatments to be evaluated have not been selected. Hence, a generalized master plot design will be delineated at each study site. The master plot design will accommodate one or more soil and vegetative treatments developed during Phase I.

The objective of the Phase I column studies is to formulate a suite (best combination) of soil amendments for neutralizing toxic metals in the six waste types (each waste type is represented by one of the bulk samples). This suite of soil amendments will be applied to plots in the field, allowed to equilibrate, and plots will be seeded in the late fall of 1988. Amendments will be incorporated into soils using 1) standard agricultural equipment (plow, disc, harrow), 2) using a mechanical deep-incorporation tool (deep plow, deep rotary mixer), and 3) using pressure injection. A brief background on each deep-incorporation method is attached (Appendix C). Variable coversoil thickness over amended waste will also be evaluated as a soil treatment. A coversoil "wedge" varying from 0 to 18 inches in thickness will be installed. This treatment design has been successfully used by a variety of investigators (Barth and Martin 1980). Plots will be large enough to evaluate two species mixtures. If after the outcome of Phase I greenhouse tests, only a single species mixture is recommended, the plot size can be reduced to reduce field implementation costs. Field plots will be replicated four times at each site.

The arrangement of plots will facilitate statistical interpretation of field response to soil and vegetative treatments. Soil response parameters to be measured include water content changes (including an estimate of ground water recharge), changes in soil chemical properties, and changes in soil pore water chemistry. It is felt that these parameters do not need to be evaluated independently on separate vegetative treatments. Vegetation response

parameters will include germination, establishment, cover, and yield (second year) of each seeded species. In addition, metal content of forage will be measured. A split-plot statistical design with two factors (soil and vegetative treatments) is best-suited for this experiment (Snedechor and Cochran 1978).

Figure 4.1 illustrates the master plot design for the Phase II STARS field plots. There will be five primary soil treatments including a 1) control, 2) agricultural implement incorporation (6 inch depth), 3) a mechanical deep-incorporation treatment (18 inch depth), 4) a pressure slurry injection treatment (entire depth of waste deposit plus contaminated soil), and 5) a 0 to 18 inch thick topsoil wedge over waste amended to 6 inches in depth. A sixth plot will be designed into the experiment for any additional treatments that investigators may want to test after completion of the Phase I activities. One possible use of the sixth plot would be for evaluation of a second suite of soil amendments using one incorporation technique. Certain treatments are not likely to be necessary on some sites. Cover soil is not expected for the buried soil or flood-affected soil. Pressure-injection of lime is not likely to be warranted in the flood-affected soil. These treatments will be deleted from the master plot design at these sites.

Soil treatments will be installed in 16 by 20 foot plots. This plot size was selected to be large enough to measure treatment effects on leachate quantity and quality. The six soil treatment plots will be separated by an eight foot buffer zone to allow machinery access and to avoid overlapping treatment effects. The relative placement of the soil treatments will be selected randomly. Two alternate arrangements of the six plots (which together form one replicate or "block") are shown in Figure 4.2. Depending on the pattern of spatial variability found in task 1, block dimensions can be either 20 by 150 feet, or 50 by 80 feet. Vegetative treatments will be installed using a "split-plot" technique where one-half the plot is seeded into each species mixture. The portion of the plot used for a particular species will be randomized.

The statistical method used to compare results from each treatment is called analysis of variance (Snedecor and Cochran, 1978). The analysis of

variance model used to analyze vegetative response is shown in Table 4.1 while that used for evaluation of soil response is shown in Table 4.2. Results from the cover-soil treatment plots will be analyzed in a separate analysis of variance where increasing cover-soil depths are treated as separate treatments.

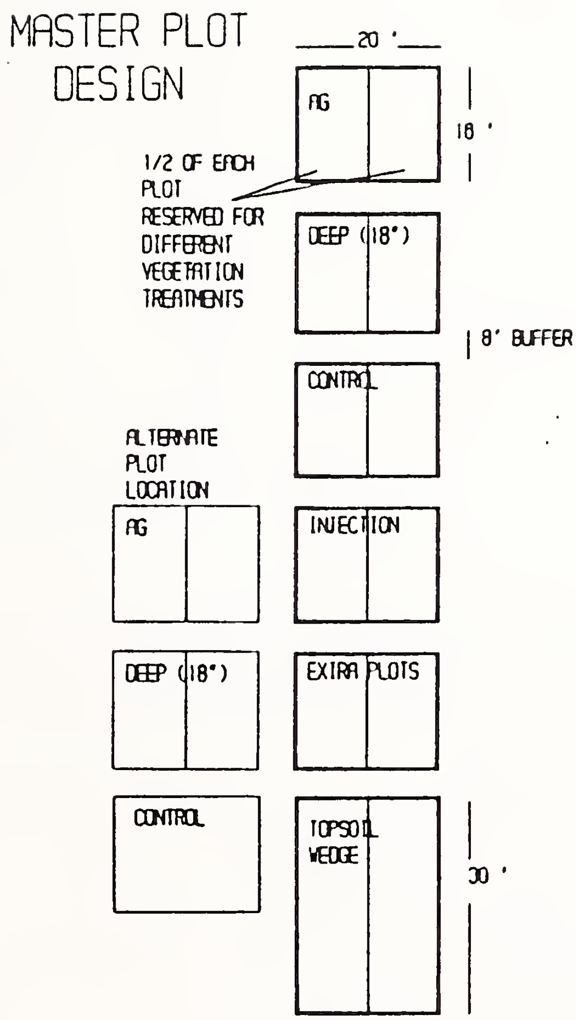


Figure 4.1. Master plot design for the Phase II STARS field study.

Table 4.1. The analysis of variance model used to evaluate vegetative results from the STARS Phase II field investigation.

Source	n	Degrees of Freedom	F value
Soil Treatments	5	4	MS/Error MS
Species Treatments	2	1	MS/Error MS
Soil X Species Interaction	10	9	MS/Error MS
Blocks	4	3	-
Error		22	-
Total Plots	40		

Table 4.2. The analysis of variance model used to evaluate soils results from the STARS Phase II field investigation.

Source	n	Degrees of Freedom	F value
Soil Treatments	5	4	MS/Error MS
Blocks	4	3	-
Error		12	-
Total Plots	20		

At each field location, four replicate sets of treatment, blocks, will be delineated in homogeneous areas with chemical properties similar to the bulk sample collected from the site. The plot locations will be staked, and the relative elevation of plot corners will be surveyed into a local datum for control. Base maps showing plot location will be at the same scale as maps prepared in task 1.

4.3 Task 3: Preliminary Sampling

Samples will be collected from plots for four purposes including 1) to measure chemical and physical parameters required for design of soil amendment rates, 2) to measure levels of plant nutrients to design initial fertilizer rates, 3) to measure total metal levels for verification of XRF results, and 4) to archive samples representative of baseline (pre-amendment) conditions for later soil chemical analyses. Archived samples will be analysed for parameters to be described in the STARS Monitoring Sample Analysis Plan (SAP). Analyses will be conducted before appropriate holding times are exceeded. Liming rates will be developed for each individual plot using the equation 1:

$$LR = [31.25 * HNO_3\text{-}S + 15.1 * HCl\text{-}S + SMP] * 1.25 \quad (1)$$

where LR = lime rate (expressed as 100% calcium carbonate effectiveness in tons/acre - 6 inch layer)

HNO_3-S = nitric acid extractable S (sulfide S) in percent

HCl-S = weak HCl extractable S (acid-forming sulfate salts) (%)

SMP = SMP buffer lime test in tons/acre (for active acidity, see QAPP)

1.25 = a design safety factor to allow for incomplete mixing and for analytical error.

Samples will be collected from throughout the zone of amendment incorporation. All plots will be sampled from 0 to 6 inches. The mechanical deep-incorporation and pressure-injection plots will also be sampled from 6 to 18 inches in depth. Finally, the pressure-injection plots will be sampled from 18 to 48 inches. Cover-soil from an offsite source of material will be

sampled for analysis. Cover-soil material will be representative of material widely available site-wide for remedial clean-up. Since soil material is not likely to be available in adequate quantities, alluvial material which is commonly found throughout the site will be used.

For 0-6 inch samples, a 1-inch diameter stainless steel core sampler will be used to collect at least 60 cores distributed throughout the each individual plot. The individual cores will be composited and mixed. Four splits will be taken from the composite sample for analysis of total metals, plant nutrients, sulfur fractions, and an archive. A hydraulically-driven 2-inch diameter King-tube will be used to collect deeper samples from four locations per plot. These samples will be composited then split similar to the 0-6 inch samples.

Samples for nutrient analysis will be split from individual plot samples and then composited by block to reduce the number of analyses. A fertilizer rate for each replicate set of treatments will be assembled based on results of these analyses.

The number and kinds of samples to be collected and analyzed is described in section 8 (Table 8.5). A detailed discussion of the quality assurance procedures and laboratory methods to be used is provided in the STARS Phase I QAPP (MSU and Schafer and Associates 1987a), the STARS LAP (MSU and Schafer and Associates 1987b), and in a CLP analytical request document (MSU 1988) which has been submitted.

4.4 Task 4: Preliminary Field Testing of Soil Amendments

The purpose of Transition Phase activities before field implementation of the STARS plots is to facilitate timely completion of the STARS project. Early results from the column studies indicate that use of a combination of quicklime or hydrated lime with agricultural lime may substantially increase pH and reduce metal mobility. Water must be added to facilitate the reaction of these amendments with waste materials. The amount of water to be added is uncertain. The ability to mix amendments through tillage is affected by the

physical condition of wetted amended soils. The physical condition of wetted soils is uncertain. The rate of change of pH after amending field soils is also unclear.

On four of the six soils tested in Phase I STARS $CaCO_3$ (agricultural lime, the commonly used neutralizing amendment for treating acid soils) was less effective in increasing pH and reducing metal levels in leachate than either $Ca(OH)_2$ (hydrated lime) or CaO (quicklime). Typical results are shown in Table 4.3. The metal release for tailings type 1 without an amendment (control) was reduced substantially through use of either $CaCO_3$ or $Ca(OH)_2$. For tailings type 3, $CaCO_3$ was not effective in reducing metal levels sufficiently while $Ca(OH)_2$ was effective. Initially, the reason for the better efficiency of $Ca(OH)_2$ was thought to be the higher pH achieved. It was also recognized that this elevated pH would not persist in the field. The reactions shown below (equations 2-5) happen in the field so that after a period of equilibration, a $Ca(OH)_2$ amended soil should be identical chemically to a $CaCO_3$ amended soil.

Table 4.3. Preliminary column study results for waste type 1 and waste type T.

Waste Type	Amendment	Saturation (%)	pH	EC (mmhos/cm)	Cu	Zn	As
					---- (mg/kg soil)----		
1	Control	29.6	4.2	1.36	108.	118.	.0037
	$CaCO_3$	31.0	7.3	2.30	0.15	0.48	.0053
	$Ca(OH)_2$	40.5	11.5	1.56	1.34	0.02	.062
	$Ca(OH)_2 + CO_2$	30.0	7.0	2.42	0.52	0.97	.010
T	Control	34.2	4.4	1.45	798.	2113.	.037
	$CaCO_3$	38.9	6.7	2.80	18.	1331.	-
	$Ca(OH)_2$	44.0	12.0	6.70	1.3	1.0	.0059
	$Ca(OH)_2 + CO_2$	47.4	7.8	2.11	0.27	0.31	.026

$$Ca(OH)_2 = Ca^{++} + 2\ OH^- \quad (2)$$

$$OH^- + CO_2 = HCO_3^- \quad (3)$$

$$HCO_3^- + OH^- = CO_3^{--} + H_2O \quad (4)$$

$$CO_3^{--} + Ca^{++} = CaCO_3 \quad (5)$$

Investigators have shown that a soil in equilibrium with solid $CaCO_3$ and atmospheric levels of dissolved CO_2 should have a pH of 8.3 to 8.5 (Garrels and Christ, 1965). Presence of sodium will elevate this to near 9.3, while presence of more soluble sources of Ca (gypsum) may lower the pH to 7.5. The time required for the elevated pH in a $Ca(OH)_2$ amended soil to drop from 12 to 8 has been reported to be as long as 12 months or more Figure 4.2.

In the column studies CO_2 gas was introduced to soil slurries to increase the reaction rates of the equations shown above. When $Ca(OH)_2$ was added and was reacted to form $CaCO_3$, the reduction in metal solubility was equivalent to unreacted $Ca(OH)_2$. It appears that there is an advantage to raising the pH above 10 ("over-neutralization") and allowing it to drift back to an equilibrium level near 8. The formation of $CaCO_3$ in-situ may scavenge metals out of the system by co-precipitation. Added $CaCO_3$ may be coated by iron oxides in very acid soils thus limiting reactivity. The higher solubility of $Ca(OH)_2$ may alleviate the coating phenomenon. Despite specific mechanisms, column studies indicate that $Ca(OH)_2$ or CaO must be added to achieve over-neutralization if metal levels are to be reduced.

In this task the combined use of smaller fractions of $Ca(OH)_2$ or CaO to achieve immediate pH control with the remaining long-term lime requirement satisfied by an addition of $CaCO_3$ will be tested. Serial application of $Ca(OH)_2$ or CaO in combination with $CaCO_3$ may reduce the persistence of high pH

levels in treated soils. The effects of various lime treatments on soluble metal levels will also be investigated.

Soil amendment microplots (1 x 2 meters) will be installed on two sites (tailings type 1 and 3), one which responded well to $CaCO_3$ application and one which did not. Treatments will include a 1) control, 2) $CaCO_3$, 3) $Ca(OH)_2$, 4) $CaCO_3/Ca(OH)_2$ blend 1, 5) $CaCO_3/Ca(OH)_2$ blend 2, 6) one other amendment strategy developed in the column investigations. Amendment rates will be calculated based on the sulfur fractions and level of active acidity usnig equation 1. These treatments will be incorporated both dry and wetted. There will be a total of 24 microplots. There will no replication of treatments. The soil treatment process will be recorded on video to assist co-workers involved in the project in adapting these preliminary field tests to full-scale plot implementation methods using heavy equipment.

Preliminary laboratory tests will be run to determine the quantity of water required for the lime materials to adequately react with soil material to cause an elevated pH response. In the field, amendments will be spread by hand and incorporated dry with rear-tine garden roto-tiller. Mixing will be assessed by applying phenylthaline solution to a cross-section of amended soil. High pH soil zones will turn pink. The wetted plots will have water added from a metered source of water brought to the site in a truck-bed mounted water tank with pump.

Measured response of these treatments will include pH, EC, and metal (Cu, Zn, As, Mn, Cd) levels measured before treatment, immediately after treatment and 2 months after treatment.

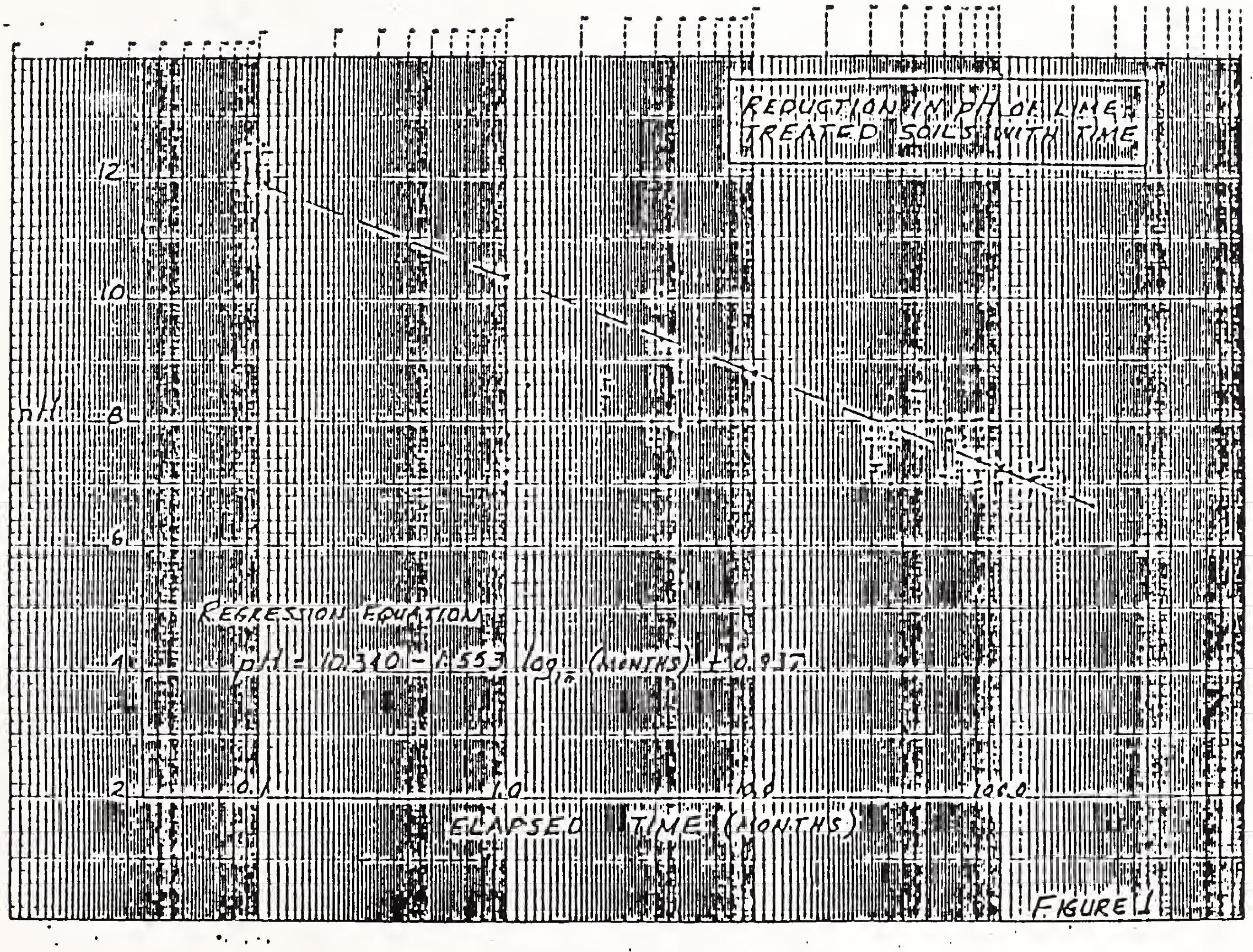


Figure 4.2. Changes in pH of $Ca(OH)_2$ amended clay soils (from McElroy, Charles. 1982. Effectiveness of dispersed clay treatments. Progress Report. Soil Mechanics Laboratory. USDA South National Technical Center. Ft. Worth, TX. 73p.

4.5 Task 5: Soil Amendment Incorporation

4.5.1 Plot Design

Soil amendments and species mixtures designed during the on-going Phase I STARS bench-scale investigation will be implemented in the field plots at five field sites. If homogeneous plot areas cannot be located at a candidate site during the Transition Phase field activities, then an alternative site location may be substituted for that waste type.

4.5.2 Specialized Equipment and Resources

A number of resources must be mobilized in a timely manner to implement the field plot construction. Soil amendments and plant materials used in the Phase I STARS investigation were selected partly on the basis of cost and availability. These resources should be readily obtained for field implementation. Specialized heavy equipment will be needed for mechanical deep incorporation, and pressure-injection of amendments. A substantial amount of grading may be required to remove fill material from some sites and to prepare a cover-soil wedge for each site. Cover-soil material typical of that available in large quantities along Silver Bow Creek will need to be acquired and tested for nutrient status.

Equipment for pressure injection is largely proprietary and requires subcontracting with firms specializing in pressure injection. The subcontracting procedure has already been initiated for pressure injection. It is anticipated that other heavy equipment can either be leased and operated by project personnel or bids for plot contruction will be obtained from companies with personnel that are trained to work on hazardous waste sites. This precludes the need extensive subcontracting and for specialized health and safety training for equipment operators. A summary of specialized equipment and resources is presented in Table 4.4.

Table 4.4 Specialized equipment and resources required for implementation of STARS field plots.

ITEM DESCRIPTION	UNITS	COST/UNIT	COST
Equipment			
D-8 Caterpillar (or equivalent) site prep	24hrs	$125/hr	$3,000
D-8 Caterpiller (or equivalent) deep incorp	60 hrs	$125/hr	$7,500
Rear-dump trucks (cover-soil hauling)	170yds	$12/yd	$2,040
Front-end loader	24hrs/site	$50/hr	$6,000
Water truck	1000 gal/site	$0.1/gal	$5,000
Farm Tractor	20hrs/site	$50/hr	$5,000
Hydraulic Soil Auger (Giddings or equivalent)			
Deep Mechanical incorporation unit			
(Alberta deep plow or equivalent)	15	$100/day	$1,500
mobilization			$2,400
Pressure washer (decontamination)	45	$ 45/day	$2,025
Water tank (decontamination)	45	$ 10/day	$450
Pressure injection (subcontracted) *		-	- *
Materials			
Quicklime	-	$ 70/ton	- *
Hydrated Lime	20 tons	$ 60/ton	$1,200
Agricultural Lime	80 tons	$ 40/ton	$3,200
Ferric sulfate	4 tons	$275/ton	$1,100
Miscellaneous seed, plant material, and fertilizer		-	$2,000

* costs for separate subcontracts not shown

4.5.3 Construction Methods

Improved access roads will be constructed to facilitate mobilization of equipment on each site. Non-road natural areas disturbed during construction of the plots will be seeded after completion of plot construction. Rough grading of the field plots will be performed to ensure adequate drainage of surface water off the plots. Where non-tailings fill material has been placed on the surface, it will be removed from the plot area, stockpiled on-site, covered with a thin soil cap and seeded. Soil amendments for the agricultural and deep mechanical incorporation plots will be surface-applied using a manually-operated drop-type fertilizer spreader modified to accommodate high application rates of low density material (lime).

A farm tractor with moldboard plow will be used for the agricultural implement incorporation. At least two passes of the plow in opposite directions will be used to ensure adequate mixing. Additional passes may be required if indicated by construction supervision of pH response (refer to next section). Where addition of water is required for the hydration reaction of added lime, water will be applied to the plots from a water truck. As the lime slakes, the amended soil material should dry sufficiently to allow additional tillage to better ensure amendment mixing. Water from Silver Bow Creek will be used for hydration. Reserved water will be obtained from a water right held by Dan Ueland who lives adjacent to the study area.

A D-8 Caterpillar tracked bulldozer (or equivalent) will be used to provide deep mechanical incorporation. The plowing method will be modified to maximize the degree of amendment mixing achieved. Two passes of the plow will be used if necessary to achieve adequate mixing. Other amendment incorporation strategies will be adapted to use with deep mechanical incorporation (ie. spray fluid lime onto furrow during tillage) during Phase II of the STARS investigation. For deep amendments requiring water for hydration, water will be applied and the plots re-tilled similar to the approach used for the agricultural incorporation method.

For the cover-soil wedge area, amendments will be worked into soils using the agricultural amendment incorporation technique. The cover-soil wedge will

range from 0 to 18 inches in depth. A portion of the cover-soil plot will have zero cover-soil thickness to allow comparison of species response with no cover-soil to response with various cover-soil thicknesses.

Lime slurry pressure injection (LSPI) was pioneered by the Woodbine Corporation as a method for increasing soil strength of expansive clay soils using in-situ modification of native soil material (Boynton and Blacklock n.d., Appendix D). A slurry of slaked quick-lime is mixed on-site in a 17,000 gallon tanker-based batch plant. An injector rig typically consists of a tracked vehicle with a gang of 20 foot long tubes (1-2" diameter) spaced on five foot centers. The rods, with an orifice in the tip, are advanced hydraulically into soil material. At selected depth intervals, the quicklime slurry is injected under pressure (>1000 psi) into the soil matrix. In treated expansive clay soils, lime fills cracks at great distances (>5 feet) from the injection site. The LSPI technology will be used for the deep-pressure injection plots. Amendments to be injected will be provided by the results of the Phase I STARS project. Field plot construction will be supervised to determine if the LSPI technology can achieve an adequate degree of mixing of amendments into contaminated media.

After incorporation of all amendments, all plots including the control will be disced to loosen and prepare the seedbed. Discing will break up large clods left by deep mechanical incorporation and agricultural plowing. After seeding, plots will be fenced to exclude grazing and to protect the plots from disturbance by off-road vehicle use.

4.5.4 Construction Supervision

Adequate amendment mixing and pH control is essential to the successful reduction in metal mobility required in the STARS plots. To better ensure the success of the plot construction, construction supervision will be used to measure pH response and degree of amendment mixing. After completion of all initial amendment incorporation (and addition of water if applicable) samples will be collected from at least four random locations from each plot (but at least 3 feet from plot edges) and paste pH readings determined. The mean pH

level should be above target levels (7.5 to 8.0) for the amended plot area. If pH levels are below the target, then additional tillage, addition of more water, or addition of more amendment will be used to bring pH to the target level. Shallow soil observations will be excavated to observe the degree of mixing of lime amendments. An indicator dye and $BaSO_4$ powder (to show dye color) will be spread on the face of the excavation to indicate the variability in pH level. Supervision of all amendment incorporation operations and addition of water will be supervised by an on-site inspector at all times.

4.6 Task 6: Plot Seedbed Preparation, Fertilization, and Seeding

After construction and amendment of the field plots, at least one month will be allowed for chemical reactions to reach equilibrium and for pH values to reach levels below 9.0 before seeding is initiated. Fertilization will be necessary and recommendations for each replicated block of treatments will be developed based on results of nutrient tests. Macronutrient concentrations in the wastes must not be raised to medium or higher levels. Nitrogen and phosphorus must be maintained at "low" levels to prevent excessive germination and growth of weedy species. Therefore, 2 to 4 ug/g potassium chloride extractable nitrate-nitrogen in the plow layer is adequate for the species recommended for seeding on the wastes. Phosphorus concentrations should also be maintained at low levels. Bray extractable phosphorus should range from 6 to 15 ug/g in the plow layer.

Fertilizer nitrogen and phosphorus will be supplied by a mixture of mono-ammonium phosphate (11% N - 51% P_2O_5 - 0% K_2O), and ammonium nitrate (34% N - 0% P_2O_5 - 0% K_2O), while boron will be supplied as borax. Fertilizer will be incorporated into the root zone and a seedbed will be prepared on all plots by discing and harrowing. This activity will create a firm but roughened surface.

The selected mixture of species will be broadcast seeded on all plots at a total rate of 50 seeds/ft^2 or more. The composition of the seed mixes will be determined by Phase I investigation. Tentative seed mixes for each tailings type are shown in Table 4.5.

Table 4.5 Tentative recommended seed mixes for STARS tailings types.

Waste Type	Vegetation: Scientific Name	Vegetation: Common Name
1	Poa compressa	Canada bluegrass
	Agropyron trichophorum	Pubescent wheatgrass
	Festuca ovina	Sheep fescue
	Deschampsia caespitosa	Tufted hairgrass
	Elymus angustus	Altai wildrye
	Elmyus cinereus	Basin wildrye
	Agropyron smithii	Western wheatgrass
2	Calamovilfa longifolia (Goshen)	Prairie sandreed
	Deschampsia caespitosa	Tufted hairgrass
	Elymus giganteus	mammoth wildrye
	Festuca ovina	Sheep fescue
	Poa compressa	Canada bluegrass
3	Deschampsia caespitosa	Tufted hairgrass
	Elymus angustus	Altai wildrye
	Elymus cinereus	Basin wildrye
	Agropyron Smithii	Western wheatgrass
	Agropyron trachycaulum	Slender wheatgrass
In-place Tailings	Agropyron trachycaulum	Slender wheatgrass
	Agropyron smithii	Western wheatgrass
	Calamovilfa longifolia (Goshen)	Prairie sandreed
	Deschampsia caespitosa	Tufted hairgrass
	Elymus cinereus	Basin wildrye
	Festuca ovina duriuscula	Hard sheep fescue
	Poa canbyi	Canby bluegrass
Flooded Agricultural Lands	Agropyron smithii	Western wheatgrass
	Agropyron trachycaulum	Slender wheatgrass
	Elymus cinereus	Basin wildrye
	Elymus angustus	Altai wildrye
	Stipa viridula	Green needle grass

Seeding will be performed after October 15, but before ground freeze to insure that the seeds remain dormant over the winter avoiding potential cold-injury to seedlings. A "dormant seeding" such as this insures the best possible stand establishment and vigor in new seedings. immediately after seeding, plots will be drug or cultipacked to cover seed and to insure adequate soil to seed contact. if an early cold spell freezes the ground so that it cannot be seeded, the plant propangules will be stored in the seed storage facilities of the Plant Growth Center at Montana State University. Seeding will subsequently take place during April, 1989. Prior to broadcast seeding in the spring, the plots must be chiseled to prepare the new seed bed.

5.0 RESPONSE VARIABLES

The scope of this work plan includes only those Phase II STARS activities through fall seeding in 1988. Samples collected in conjunction with plot construction are described. Additional samples and field monitoring data will be collected in order to monitor the response of the plots. A monitoring phase work plan will be developed to cover all aspects of monitoring of plot response.

Monitoring of a number of significant response variables is required to measure the effectiveness of this remedial treatment in order to provide the kind and quality of data required for the feasibility study analysis of alternative remedial measures (see section 9.0, Data Analysis and Interpretation). The goal of monitoring the plots is to measure the effectiveness of treatments in abating metal movement into surface and groundwater, to measure the stability of the revegetated system, and to develop field scale implementation methods for STARS remedial treatments.

Samples of soil and vegetation will be taken after amending and seeding plots to assess the effects of treatments on soil chemical properties and on plant uptake of metals. Plant performance will be measured quantitatively on all plots. The chemistry of leachate will be monitored through use of suction lysimeters installed at selected depths. The quantity of leachate will be measured through development of a water budget for the plots. Precipitation, and soil water content will be measured, and evapotranspiration will be estimated from other climatic properties (temperature, solar radiation) in order to develop a water budget. Runoff rates and chemistry of runoff will be measured. Examples of the kinds of data to be collected during field monitoring are listed in Table 5.1.

Table 5.1. Response variables to be evaluated in the Monitoring Phase of the STARS field investigation.

MEDIA	RESPONSE VARIABLE	UNITS	TYPICAL METHOD
Vegetation	Germination	plants/m^2	stand counts
	Establishment	plants/m^2	stand counts
	Production	g/m^2	total biomass
	Cover	(%)	visual estimate
	Metal levels	mg/kg tissue	HNO_3 digest/ICP
Soil Chemistry	Total Metals-baseline	mg/kg soil	HNO_3/H_2O_2 digest
	Extractable metals-baseline	mg/kg soil	NH_4OAc pH 5.5
	Extractable metals-treated	mg/kg soil	same
	Soluble metals-baseline	mg/kg soil	water extract/ICP
	Soluble metals-treated	mg/kg soil	same
	Organic matter level	(%)	wet digestion
	pH/EC	SU,mmhos/cm	electrochemical
Leachate	Quantity	mm/year	water budget, model, neutron probe.
	Metals, major ions	ug/l	suction lys/ICP,FAA
Runoff	Quantity	cm/hr	rainfall simulation
	Metals, major ions	ug/l	RF simulation/ICP

6.0 SAMPLING PLAN

The scope of this work plan includes only those Phase II STARS activities through fall seeding in 1988. Samples collected in conjunction with plot construction are described in this work plan. Standard Operating Procedures (SOP's) are attached in Appendix A listing methods to be used for soil description, soil sampling, XRF spectrometer measurements, measurement of pH, and EC, and for sample handling. Detailed sample collection procedures are presented within subtask descriptions (section 4.0). The quality assurance program to be implemented is discussed in section 8.0.

Additional samples and field monitoring data will be collected after plot construction in order to monitor the response of the plots. A monitoring phase work plan will be developed to cover all aspects of monitoring of plot response. A specific sampling plan including sampling methods, media to be sampled, sampling schedule, and number of samples will be developed in conjunction with the STARS Monitoring Sample Analysis Plan (SAP).

7.0 ANALYTICAL METHODS

Analytical methods referenced in this document are described in detail in the STARS Laboratory Analytical Protocol (LAP) document (MSU and Schafer and Associates 1987a). Quality assurance and data quality objectives for the STARS investigation are described in the STARS Quality Assurance Program Plan (QAPP) document (MSU and Schafer and Associates 1987b).

8.0 DATA MANAGEMENT AND DATA QUALITY OBJECTIVES

8.1 Quality Assurance Program Overview

Data can vary in quality due to sampling methodology, sample preparation, analytical procedures, laboratory quality control, and available documentation. In order to develop a reliable data base which can be used for development of remedial alternatives for this RI/FS, standards have been developed for data quality, and chain-of-custody controls. To meet this objective a project Quality Assurance Project Plan (QAPP), (MSU and Schafer and Associates 1987b) for the STARS project has been prepared. Field and laboratory methods proposed for use in this investigation are described in the STARS LAP (MSU and Schafer and Associates 1988a). The results of the STARS - Transition Phase, Phase II and the monitoring phase will be used to support the selection of this remedial alternative. Results of these in-situ treatability studies may also be used on other studies with similar characteristics. Sampling and analyses for tests used to develop predictive results need to be carried out with the same levels of accuracy and precision that were established during the STARS - Phase I effort. (See STARS Phase I QAPP and LAP documents for details).

8.2 Data Users

The primary decision makers and data users for the STARS investigation are:

Decision Makers:

Kathy Demarinis - Project officer/ MDHES
Scott Brown - RPM/USEPA
Dave Bunte - SPM/CH2M HILL

Primary Data Users:

Dennis Neuman and staff - SSPM/RRU, MSU
Bill Schafer and staff - SSPM/Schafer and Associates

The primary data users are those individuals involved in the ongoing RI//FS activities for STARS. The primary data users for this site are the SPM and the subcontractors and their personnel. The RPM and the SPM will work in a parallel fashion and be continually involved with the technical staff through the course of the project. Primary data users will attend scoping meetings which will be used to review available data and identify the needs of the data users.

Secondary users would be any individuals of parties that rely of these data to support their activities. These parties include, but are not limited to:

- The Office of Surface Mining
- The U.S. Bureau of Mines
- The U.S. Geological Society
- Counties and municipalities in which Silver Bow Creek flows
- EPA's Mine Waste Group
- Personnel working on other CERCLA projects (especially in regions 8, 9, and 10) where STARS revegetation technology may be useful

8.3 Data Uses and Needs

The primary objectives of the Streambank Tailings and Revegetation Study (STARS) are to:

GENERAL OBJECTIVE 1: Design, field test, and evaluate the response of potential remedial measures for mitigation of human health and environmental impacts from streambank tailings using chemical microencapsulation, deep incorporation, cover-soil isolation, and enhanced evapotranspiration techniques.

GENERAL OBJECTIVE 2: Develop a method of ranking tailings-contaminated areas for selecting contaminated remedial measures.

These objectives will allow the RI/FS project team to collect the required performance data to design selected innovative remedial alternatives for consideration in the feasibility study.

The specific objectives for Transition Phase and Phase II of the STARS project are to:

SPECIFIC OBJECTIVE 1: Locate and delineate field plot locations for each candidate soil or tailings (waste) investigated in Phase I column and greenhouse investigations. Suitable sites will be determined to be representative of the candidate sample, relatively homogeneous, and accessible by heavy equipment.

SPECIFIC OBJECTIVE 2: Samples will be obtained from each plot at each site and will be analyzed for those parameters necessary to design field treatments. Determination of RAS metal levels and of plant nutrient availability is also required. Splits of samples will be archived for comprehensive analysis at a later date. These archived splits will represent unamended (baseline) chemical conditions.

SPECIFIC OBJECTIVE 3: Selected soil amendments will be incorporated into field plots at the candidate sites using agricultural tillage implements (6 inch depth of incorporation), mechanical deep-incorporation methods (18 inches), and pressure injection methods (to 20 feet or more).

SPECIFIC OBJECTIVE 4: After waiting for chemical amendments to equilibrate for a specified period, selected acid- or metal-tolerant vegetation will be seeded into the chemically-treated plots by the fall of 1988 for a dormant seeding.

8.4 Data Types

Data types required to complete each specific objective are:

- Characterization of the mine waste materials to assess field variability at each site.

- Characterization of the mine wastes within each selected field plot to determine soil amendment rates, to design fertilizer rates, to measure total metal levels for verification of the field XRF results, and to determine pH, EC, and texture. These will be used to assess field plot homogeneity.

- Preliminary field testing of soil amendments.

Table 8.1 Summarize these data types with respect to necessary parameters. Descriptive data gathered at each sampling location with help determine homogeneity of the selected plots. The physical and chemical nature of the mine waste materials must be known in order to select subplots for implementation of the different treatments.

Table 8.1. Data Uses, Objectives, and Types for STARS Transition Phase

Data Uses	Objectives	Data Types & Parameters
Assessment of Field Variability	To locate and delineate field plots within each site	Field pH Field EC Field XRF Measurements Depth of Waste (tailings) Depth to ground water Proximity to Silver Bow Creek
Assessment of Field Plot Homogeneity	To design waste(tailings) amendment rates	SMP lime buffer requirement modified acid-base account
	To design fertilizer requirements and rates	Nitrate-nitrogen Phophorus Potassium Boron
	To verify field XRF measurements of metals in wastes	Total metals in wastes(tailings)
	To evaluate physico-chemical properties	pH EC Texture
Preliminary Field Testing of Waste Amendments	To evaluate transition from bench-scale to pilot-scale in the field	pH EC Soluble As,Cd,Cu,and Zn Physical condition of wetted wastes Water requirements

8.5 Data Quality

Table 8.2 summarizes the analytical levels, types of analyses, limitations of the analyses, and data quality for the various data uses. The data will be used to assess homogeneous and representative subplots at each field site, choosing alternatives, and for designing the field trials. Mine waste characteristics and contaminants of particular concern are pH, EC, total Al, As, Cd, Cu, Mn, Ni, Pb, Zn, and sulfur species. Other significant characteristics are levels of plant-available nutrients including N,P,K, and boron (B), and water soluble levels of As, Cd, Cu, and Zn. Laboratory QC requirements for detection limits, laboratory spike recovery, laboratory duplicate analysis, and laboratory control sample analysis are given in Table 3A of the STARS QAPP Document.

Table 8.2. Summary of analytical levels appropriate to data uses, STARS (Phase II)

Data Uses	Analytical Level	Type of Analysis	Limitations	Data Quality
-Site Characterization -Monitoring During Phases	Level I	-Descriptive (field guides) -Field instruments	-Subjectivity of descriptive data	-Quality of descriptive data depends on experience of sampler -If instruments are calibrated and data interpreted properly can provide reliable screening type data
-Evaluation of Alternatives -Monitoring During Phases -Engineering Design for Field Trials	Level III	-Inorganics using EPA procedures other than can be analyte specific -Physical parameters -Vegetation parameters	-Tentative ID in some cases	-Similar detection limits to CLP -Less rigorous QA/QC than level IV
-Evaluation of Alternatives -Engineering Design for Field Trials	Level IV	-Inorganic by GC/MS,AA, ICP -Low ppb detection limit	-Some time may be required for validation of packages	-Goal is data of known quality -Rigorous QA/QC
-Evaluation of Alternatives -Engineering Design for Field Trials	Level V	-Non-conventional parameters -Method-specific detection limits -Modification of Existing Methods	-May require method development modification -Lead time necessary to obtain special services	-Method specific

8.6 QA/QC Objectives

The overall quality assurance objective for measurement data is to ensure that data of known and acceptable quality are provided. The data will be of the quality to withstand the scrutiny of litigation. In order to meet these objectives, the following QA/QC parameters will be addressed for data measurements:

- o Comparability
- o Completeness
- o Representativeness
- o Accuracy
- o Precision

Overall precision and accuracy targets for chemical contaminant measurements have been set at 90 percent confidence with a 10 percent deviation. Comprehensive implementation procedures for precision and accuracy assurance are referenced in the QAPP (MSU and Schafer and Associates 1987).

8.7 Quality Control

To measure the precision and accuracy of laboratory data for samples collected the following field quality control sample protocols have been established (Table 8.3):

Table 8.3. Generalized QA/QC steps for mine waste samples.

1) Replicate samples will be inserted into the sample train at a frequency of one in twenty for waste samples. Additional replicates or other QA/QC samples will be used to provide a statistically defensible QA/QC data set for all sample runs.
2) Cross contamination blanks will be inserted into the sample train at a frequency of one in twenty, when necessitated by sampling procedures.
3) Blind standard samples will be inserted into the sample train at a frequency of one in twenty where standards are available.

The Standard Operating Procedure for insertion of QA/QC samples (SOP-6, Appendix A) addresses the methods and timing of QA/QC samples in greater detail.

Quantitative on-site measurements including soil and pH, EC, and XRF metal content will be subjected to QA/QC provisions to define the quality of field data. The following data verification steps will be implemented for field measurements (Table 8.4):

Table 8.4. Generalized QA/QC steps for field measurements

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1) Soil pH, SC (1:10), and XRF measurements will be performed in replicate on samples splits (1 in 20) to provide a measure of precision.

2) Instrument calibration with known standards and field checking EPA pH and SC reference materials at a frequency of 1 in 20 will be used to provide a measure of data accuracy.

3) Other on-site data collected will be replicated at a frequency of not less than 1 in 20 to provide a measure of precision. Accuracy estimates will be based on methodology cited and professional judgment due to the lack of available standards for these measurements.

8.8 Overview of Sampling and Monitoring

A number of soil samples will be submitted for laboratory analysis as part of the STARS Field Site Selection and Sampling activities. These will include 1) waste samples analyzed for properties used for design of amendment rates, 2) samples submitted for RAS total metal analysis to be used for verification of XRF data, 3) samples measured for nutrient levels (N,P,K, and boron (B))to determine fertilizer requirements, and 4) archived samples representing baseline soil chemical conditions. Samples will be collected from all plots from 0-6 inches, from 6-18 inches for the mechanical deep incorporation plots, and from 18 inches to the base of the tailings in the pressure injection plots. The approximate number of natural and QA/QC samples to be submitted are outlined in Table 8.5.

Table 8.5. Summary of samples to be submitted to a laboratory from the STARS Field Site Selection and Sampling activities.

MATRIX	SOURCE	ANALYSES	DEPTH (in)	SAMPLE TYPES NATURAL	STANDARDS	REPLICATES	CROSS-CONT. BLANKS	TOTAL
Soil	Plots	[SAS:pH,EC,SMP]	0-6	120	0	6	0	126
		[S fractions,]	6-18	40	0	2	0	42
		[texture]	18-48	20	0	1	0	21
			COVER-SOIL	5	0	1	0	6

								195
Soil	Plots	[RAS:total]	0-6	20	5	5	3	33
		[metals]	6-18	3	0	0	0	3
			18-24	2	0	0	0	2
			COVER-SOIL	0	0	0	0	0

								38
Soil	Plots	[Plant]	0-6	20	0	1	0	21
		[nutrient]	6-18	20	0	1	0	21
		[levels]	18-24	20	0	1	0	21
			COVER-SOIL	5	0	1	0	6

								69
Soil	Plots	[Archived]	0-6	120	0	6	0	126
		[(not analyzed]	6-18	40	0	2	0	42
		[at this time)]	18-24	20	0	1	0	21
			COVER-SOIL	5	0	1	0	6

								195

Samples will be collected from the microplots described in task 4 before treatment, after treatment, and two months after treatment. Samples will be analyzed for pH, EC, and soluble levels of Cu, Zn, As, Cd, and Mn. There will be 32 microplots sampled three times each resulting in 96 natural samples. An additional five QA/QC samples will also be analyzed. Due to the short time frame for this task, analyses will be performed at MSU to provide rapid turnaround time on analytical results. Analytical methods are outlined in the STARS LAP (MSU and Schafer and Associates, 1987).

8.9 Equipment

The necessary field equipment, supplies and safety equipment required to carry out the Silver Bow Creek study are presented in Table 8.5.

Table 8.6. Monitoring, sampling and safety equipment list for the Silver Bow Creek STARS investigation.

CH2M HILL	MSU, SCHAFER AND ASSOCIATES
	XRF unit rental
	(2) pH Meter and Electrode
700 ICHEM Jars - 8 ounce	pH 2, 4, 7 and 10 Buffer Standards
EPA Sample Tags - 80	(2) Conductivity Meter and Probe
SAS Packing Lists - 40	Conductivity Standards
Custody Seals - 3 boxes	EPA standards pH and SC
Chain of Custody Records - 40	1000 ml Poly Beakers - 6
Federal Express Air Bills - 40	200 ml Poly Beakers - 6
	disposable styrofoam cups for pH and SC measurement
"Fragile" and "This Side Up" Labels	NBS River sediment standard (BFS)
ITR forms - 20	Squirt Bottles
	Kimwipes
	Meter Tape
	Bucket Auger
	Oakfield Probe
	Shovels
	Hydraulic Probe

Table 8.6. (continued).

CH2M HILL	SCHAFER AND ASSOCIATES
	plastic sampling equipment
	Hand Trowel
	Plastic Ground Sheeting
	Custom Field Report Forms
	Clear Tape for Cooler Labels
	Container for Kimwipes in the Field - 2
	Masking Tape (to label jars) - 2 rolls
	Duct Tape (for inside coolers) - 5 rolls
	Distilled Water (for decontamination) - 40 gallons/field collection
	Thermometer (outdoor) - 1
	Munsell soil color book
	standard SCS soil morphology code book
	1 Inch Foam Rubber - 4 foot/cooler
	Log Book (3 ring binder) - 1
	Log Book (bound)
	Site Map
	Portable Water Jug (2 gal.)
	Paper Drinking Cups
	Cotton Coveralls - 6
	10 rubber gloves
	100 plastic booties (disposable)
	100 garbage bags (disposal)

Table 8.6. (continued).

CH2M HILL	SCHAFER AND ASSOCIATES
	Respirators (dust cartridges)
	Field health and safety manuals
	Cotton Gloves - 15 pair
	Hard Hats - 6
	Safety Glasses - 6 pair
	Boots (steel shank and toe) - 4 pair
	First Aid Kit
	Eye Wash Kit
	Fire Extinguisher
	Stretcher
	Clothes Brush
	Plastic Pails (for decontamination)
	Plastic Water Container
	Hand Soap
	Paper Towels
	Sharpies and Ball Point Pens
	35 mm Camera
	Color Print Film
	Plastic Ground Sheeting to set up Decontamination if necessary
	Funnel for Decontamination Water
	Wind Indicator Flag (surveying tape)
	Parafilm
	Handiwipes

9.0 DATA ANALYSIS AND INTERPRETATION

Data collected to evaluate the STARS Phase II field investigation will be sufficient to evaluate the STARS remedial alternative in light of the nine criteria used for analysis of alternative remedial measures under SARA RI/FS guidance (Table 9.1). A control (unamended, seeded) plot will be used at all sites so that treatment response can be compared against a "no action" alternative. In addition, treatment effectiveness will be compared to contaminant specific ARAR's developed for the site. The primary effect of a STARS treatment would be in reducing mobility of contaminants, although some reduction in surface concentration of contaminants could result due to dilution. Hence, the impact of STARS on site ARAR's would be inferred largely by assessing the effectiveness in reducing flux of metals into ground water, surface water, and air.

Specific data collection and analysis for the STARS Phase II project will focus on those remedial alternative evaluation criteria that are least well understood including

- long-term effectiveness
- reduction of toxicity, mobility, and volume
- implementability
- cost
- compliance with ARAR's

Table 9.1 Criteria for detailed analysis of remedial alternatives in the RI/FS process mandated by SARA (from EPA, 1988)

CRITERIA FOR DETAILED ANALYSIS OF ALTERNATIVES

SHORT-TERM EFFECTIVENESS

- Protection of Community During Remedial Actions
- Protection of Workers During Remedial Actions
- Environmental Impacts
- Time Until Remedial Action Objectives Are Achieved

LONG-TERM EFFECTIVENESS

- Magnitude of Residual Risk
- Adequacy of Controls
- Reliability of Controls

REDUCTION OF TOXICITY, MOBILITY, AND VOLUME

- Treatment Process Used and Materials Treated
- Amount of Hazardous Materials Destroyed or Treated
- Degree of Expected Reductions in Toxicity, Mobility, and Volume
- Degree to Which Treatment is Irreversible
- Type and Quantity of Residuals Remaining After Treatment

IMPLEMENTABILITY

- Ability to Construct and Operate the Technology
- Reliability of the Technology
- Ease of Undertaking Additional Remedial Actions, if Necessary
- Ability to Monitor Effectiveness of Remedy
- Ability to Obtain Approvals From Other Agencies
- Coordination With Other Agencies
- Availability of Offsite Treatment, Storage, and Disposal Services and Capacity
- Availability of Necessary Equipment and Specialists
- Timing of New Technology Under Consideration

COST

- Capital Costs
- Operating and Maintenance Costs
- Present Worth Cost

PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

- How Alternative Provides Human Health and Environmental Protection

COMPLIANCE WITH ARARs

- Compliance With Contaminant-Specific ARARs
- Compliance With Action-Specific ARARs
- Compliance With Location-Specific ARARs
- Compliance With Other Criteria, Advisories, and Guidances

STATE[1] ACCEPTANCE

COMMUNITY[1] ACCEPTANCE

[1] Only very preliminary assessments of these criteria will be included in the RI/FS. They will be fully assessed in the proposed plan and the ROD.

10.0 HEALTH AND SAFETY

Health and safety plans have been developed for the Silver Bow Creek site by Schafer and Associates and MSU. Personnel to work on-site during sample collection will have received an EPA 40 hour health and safety training course for hazardous waste site workers which meets OSHA training standards. An 8-hour refresher course has been attended by all personnel. New site workers will be accompanied by a trained worker for their first 24 hours on-site. In addition, a medical monitoring plan will be in effect for all workers in accordance with OSHA requirements.

Additions and amendments to the current Health and Safety plans are required to provide protection to on-site workers from the effects of quicklime and hydrated lime (Material Safety Data Sheets attached, Appendix E). Both of these materials are corrosive and react strongly or violently with water. As a result, they are skin and eye irritants. Full dermal protection (disposable coveralls, gloves, plastic steel-toe boots) and a decontamination procedure are required for on-site workers exposed to these amendments. Full-face cartridge-type respirators with dust cartridges are also required. During other activities where elevated dust levels occur, full- or half-face respirators are required to protect against inhalation of metal-enriched dust.

11.0 RESIDUALS MANAGEMENT

The STARS treatment technology is designed for reducing mobility of inorganic contaminants in soil materials. Residuals produced through chemical reactions in contaminated soil become an integral part of the soil matrix . These residuals (metal oxides, metal carbonates, alkaline carbonates) provide the mechanism for reducing contaminant mobility.

Vegetation produced on treated wastes may be viewed as a residual. Vegetation will be sampled and tested to see if unacceptable levels of metals accumulate making forage unsuitable for livestock or wildlife use. If forage produced is deemed unsuitable for use as forage, then in the final remedial design, grazing may be excluded using institutional land use controls. It should be noted that if single plant species have unacceptable metal levels, the total dietary intake of grazing animals may be acceptable if balanced by forage which is lower in metal levels. Vegetation in the STARS field plots, if found to be potentially unacceptable for grazing, will either be fenced to exclude grazing or vegetation will be destroyed with herbicides at the conclusion of plot monitoring activities.

12.0 SCHEDULE

The schedule for implementation of the STARS Field Site Selection and Sampling activities is shown in Figure 12.1. Timely initiation and completion of these activities are essential to maintain the overall STARS project schedule.

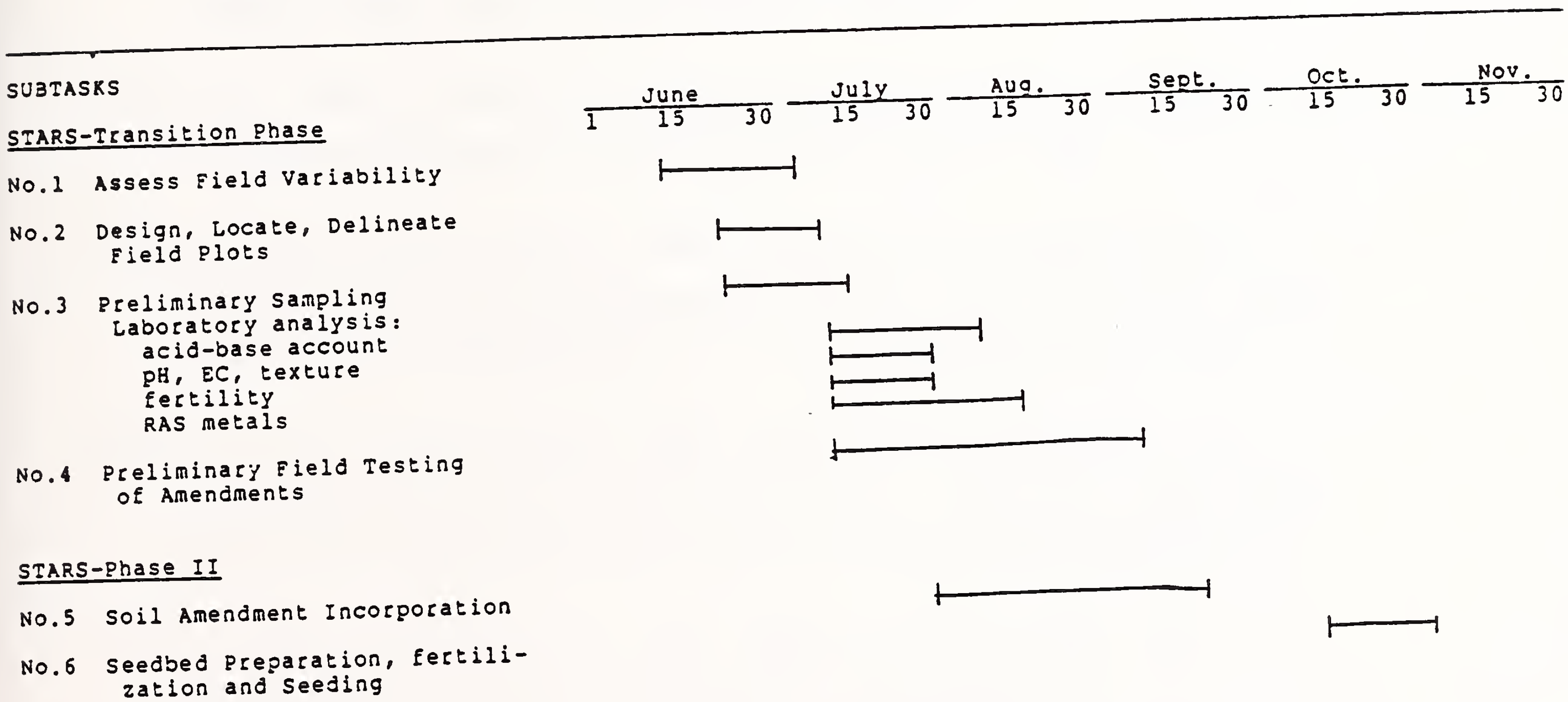

Figure 12.1 STARS Field Site Selection and Sampling schedule.

13.0 LITERATURE CITED

Barth, R.C. and B.K. Martin. 1981. Reclamation of Phytotoxic Tailings. Colorado School of Mine Research Institute, CO.

EPA. 1983. Methods for Chemical Analysis of Water and Wastes. EPA 600/4-79-020.

EPA. 1988. Draft guidance for conducting remedial investigations and feasibility studies under CERCLA. Office of Emergency and Remedial Response, Office of Solid Waste and Emergency Response, Wash. D.C. (review Draft)

Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper, and Co. San Francisco. 450 p.

MSU. 1988. Special Analytical Services (SAS) CLP Request for analyzed tailings from selected subject locations. 28 April 1988.

MSU and Schafer and Associates. 1987a. Laboratory Analytical Protocol. Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS. Submitted to EPA Region VIII. Doc. No. SBC-STARS-LAP-F-RI-121187

MSU and Schafer and Associates. 1987b. Quality Assurance Project Plan. Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS. Submitted to EPA Region VIII. Doc. No. SBC-STARS-QAPP-F-RI-121187

MSU and Schafer and Associates. 1988. STARS Transition Phase Technical Memorandum for the Streambank Tailings and Revegetation Studies. Silver Bow Creek RI/FS: Methods for Conducting Field Site Selection and Sampling of Phase II STARS Plots. June 10, 1988.

SCS (Soil Conservation Service). 1975. Soil Taxonomy. U.S. Government Printing Office, Washington DC.

Snedecor, G.W. and W.G. Cochran. 1978. Statistical Methods. 6th edition.

APPENDIX A

STREAMBANK TAILINGS AND REVEGETATION STUDY

STANDARD OPERATING PROCEDURES

SOP 1: SAMPLE pH

SOP 2: SAMPLE EC

SOP 3: SOIL HAND TEXTURE

SOP 4: SOIL SAMPLE COLLECTION

SOP 5: SOIL DESCRIPTION

SOP 6: QA/QC SAMPLES AND DOCUMENTATION

SOP 7: PRESERVING AND SHIPPING SAMPLES

XRF CALIBRATION/OPERATION

SOP 1
SAMPLE PH MEASUREMENT

Summary of Method

The pH of each sample will be determined electrochemically, using a glass combination electrode and a portable field pH meter with temperature compensation.

Sample Handling

Soil samples will be placed in styrofoam cups and a made into a saturation paste. Paste pH will be determined approximately 30 seconds after placing the pH electrode and thermistor in the soil paste. The measured value will be recorded on custom data forms (Appendix B). If leachate quantity is sufficient (>15 ml), a subsample will be placed in a plastic vial and pH measured directly. A form for recording data for leachates recovered from the TEMPE cells is included in Appendix B.

Interferences

The glass electrode is generally not subject to solution interferences from color, turbidity, colloidal matter, oxidants, reductants or high salinity. Sodium error at pH levels greater than 10 can be reduced or eliminated by using a "low sodium error" electrode. Coatings of oily or particulate matter can impair electrode response, but can be removed by gentle wiping or detergent washing, followed by distilled water rinsing. An additional treatment with hydrochloric acid (1:9) may be used to remove any remaining film. Interferences with pH measurements caused by temperature will be compensated for by use of an automatic temperature-compensated field pH

meter.

Apparatus

A portable Cole-Parmer (research grade) field pH meter with integral thermistor will be used. A combination glass electrode will be used.

Calibrations

The instrument/electrode system will be calibrated at two points that bracket the expected pH of the samples and are approximately three pH units or more apart. Buffers at pH 4, 7 and 10 will be available. The pH meter will also be adjusted for the temperature of the buffer solution. Calibration can be set in a EPROM chip in the field pH meter and will be checked daily for accuracy against pH buffer solutions. Results of calibration checks will be recorded on the same forms with measured pH of natural samples.

Standards

Primary EPA pH standards will be used for an additional QA/QC accuracy check at a frequency of one in 20 measurements. Standard samples will be prepared in accordance with EPA methodology.

Procedure

1. Standardize the meter and electrode system according to manufacturers recommendations.

2. Place the buffer solution into a clean glass beaker using sufficient volume to cover the sensing elements of the electrode.

3. Temperature of the solution will be recorded on the field sheets to

provide a cross-check for anamolous data.

4. After rinsing and gently wiping the electrode, if necessary, it will be immersed into the sample beaker and gently agitated at a constant rate to homogenize the liquid sample or soil suspension. A slow stirring rate will minimize the air transfer at the air/water interface. Note and record pH and temperature.

The EPA standard method (150.1) for measurement of pH in water is attached.

Calculation

pH meters read directly in pH units. pH will be recorded to the nearest 0.1 unit.

Precision and Accuracy

Precision of water and soil pH measurements will be based on readings of sample splits. Accuracy will be based on calibration checks and values for blind field standards (EPA primary standards).

pH

Method 150.1 (Electrometric)

STORET NO.
Determined on site 00400
Laboratory 00403

1. Scope and Application
   1.1 This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes and acid rain (atmospheric deposition).
2. Summary of Method
   2.1 The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode.
3. Sample Handling and Preservation
   3.1 Samples should be analyzed as soon as possible preferably in the field at the time of sampling.
   3.2 High-purity waters and waters not at equilibrium with the atmosphere are subject to changes when exposed to the atmosphere, therefore the sample containers should be filled completely and kept sealed prior to analysis.
4. Interferences
   4.1 The glass electrode, in general, is not subject to solution interferences from color, turbidity, colloidal matter, oxidants, reductants or high salinity.
   4.2 Sodium error at pH levels greater than 10 can be reduced or eliminated by using a "low sodium error" electrode.
   4.3 Coatings of oily material or particulate matter can impair electrode response. These coatings can usually be removed by gentle wiping or detergent washing, followed by distilled water rinsing. An additional treatment with hydrochloric acid (1 + 9) may be necessary to remove any remaining film.
   4.4 Temperature effects on the electrometric measurement of pH arise from two sources. The first is caused by the change in electrode output at various temperatures. This interference can be controlled with instruments having temperature compensation or by calibrating the electrode-instrument system at the temperature of the samples. The second source is the change of pH inherent in the sample at various temperatures. This error is sample dependent and cannot be controlled, it should therefore be noted by reporting both the pH and temperature at the time of analysis.
5. Apparatus
   5.1 pH Meter-laboratory or field model. A wide variety of instruments are commercially available with various specifications and optional equipment.
   5.2 Glass electrode.
   5.3 Reference electrode-a calomel, silver-silver chloride or other reference electrode of constant potential may be used.
   NOTE 1: Combination electrodes incorporating both measuring and reference functions are convenient to use and are available with solid, gel type filling materials that require minimal maintenance.
   5.4 Magnetic stirrer and Teflon-coated stirring bar.
   5.5 Thermometer or temperature sensor for automatic compensation.
6. Reagents
   6.1 Primary standard buffer salts are available from the National Bureau of Standards and should be used in situations where extreme accuracy is necessary.
      6.1.1 Preparation of reference solutions from these salts require some special precautions and handling[1] such as low conductivity dilution water, drying ovens, and carbon dioxide free purge gas. These solutions should be replaced at least once each month.
   6.2 Secondary standard buffers may be prepared from NBS salts or purchased as a solution from commercial vendors. Use of these commercially available solutions, that have been validated by comparison to NBS standards, are recommended for routine use.
7. Calibration
   7.1 Because of the wide variety of pH meters and accessories, detailed operating procedures cannot be incorporated into this method. Each analyst must be acquainted with the operation of each system and familiar with all instrument functions. Special attention to care of the electrodes is recommended.
   7.2 Each instrument/electrode system must be calibrated at a minimum of two points that bracket the expected pH of the samples and are approximately three pH units or more apart.
      7.2.1 Various instrument designs may involve use of a "balance" or "standardize" dial and/or a slope adjustment as outlined in the manufacturer's instructions. Repeat adjustments on successive portions of the two buffer solutions as outlined in procedure 8.2 until readings are within 0.05 pH units of the buffer solution value.
8. Procedure
   8.1 Standardize the meter and electrode system as outlined in Section 7.
   8.2 Place the sample or buffer solution in a clean glass beaker using a sufficient volume to cover the sensing elements of the electrodes and to give adequate clearance for the magnetic stirring bar.
      8.2.1 If field measurements are being made the electrodes may be immersed directly in the sample stream to an adequate depth and moved in a manner to insure sufficient sample movement across the electrode sensing element as indicated by drift free (< 0.1 pH) readings.
   8.3 If the sample temperature differs by more than 2°C from the buffer solution the measured pH values must be corrected. Instruments are equipped with automatic or manual

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[1]National Bureau of Standards Special Publication 260.

compensators that electronically adjust for temperature differences. Refer to manufacturer's instructions.

8.4 After rinsing and gently wiping the electrodes, if necessary, immerse them into the sample beaker or sample stream and stir at a constant rate to provide homogeneity and suspension of solids. Rate of stirring should minimize the air transfer rate at the air water interface of the sample. Note and record sample pH and temperature. Repeat measurement on successive volumes of sample until values differ by less than 0.1 pH units. Two or three volume changes are usually sufficient.

8.5 For acid rain samples it is most important that the magnetic stirrer is not used. Instead, swirl the sample gently for a few seconds after the introduction of the electrode(s). Allow the electrode(s) to equilibrate. The air-water interface should not be disturbed while measurement is being made. If the sample is not in equilibrium with the atmosphere, pH values will change as the dissolved gases are either absorbed or desorbed. Record sample pH and temperature.

9. Calculation

9.1 pH meters read directly in pH units. Report pH to the nearest 0.1 unit and temperature to the nearest °C.

10. Precision and Accuracy

10.1 Forty-four analysts in twenty laboratories analyzed six synthetic water samples containing exact increments of hydrogen-hydroxyl ions, with the following results:

pH Units	Standard Deviation pH Units	Accuracy as Bias, %	Accuracy as Bias, pH Units
3.5	0.10	-0.29	-0.01
3.5	0.11	-0.00	
7.1	0.20	+1.01	+0.07
7.2	0.18	-0.03	-0.002
8.0	0.13	-0.12	-0.01
8.0	0.12	+0.16	+0.01

(FWPCA Method Study 1, Mineral and Physical Analyses)

10.2 In a single laboratory (EMSL), using surface water samples at an average pH of 7.7, the standard deviation was ±0.1.

Bibliography

1. Standard Methods for the Examination of Water and Wastewater, 14th Edition, p 460, (1975).
2. Annual Book of ASTM Standards, Part 31, "Water", Standard D1293-65, p 178 (1976).
3. Peden, M. E. and Skowron, L. M., Ionic Stability of Precipitation Samples, Atmospheric Environment, Vol. 12, pp. 2343-2349, 1978.

SOP 2
SAMPLE EC MEASUREMENT

Summary of Method

Soil and leachate submitted for laboratory determination will have Electrical Conductance (EC) measured. The EC of a 1 to 10 soil to water suspension will be performed on soil samples where field measurements of EC are needed for sample location screening.

Electrical Conductivity will be measured using a self-contained portable conductivity meter (Cole-Parmer type). Temperature corrections will be made for solutions where the temperature is not 25°. Electrical conductivity will be reported at 25°.

Comments

The instrument will be standardized with KCL solution before daily use. Conductivity cell will be kept clean. Temperature variations and corrections generally represent the largest source of error.

Sample Handling and Preservation

Each soil sample will be prepared in styrofoam cups using a known volume measure scoop and a measured volume of water to yield a 1 to 10 soil solution ratio. The sample will be stirred and sediment allowed to settle. Specific conductance will be measured in the supernatant immediately following each pH measurement. The EC of leachate samples will be measured directly on a subsample if sample volume is sufficient (>12 ml).

Apparatus

Conductivity meter; range 1 to 10000 umhos per centimeter.

Conductivity cell; cell constant 1.0 or micro-dipping type cell with 1.0 constant. YSIH3Y03 or equivalent.

Thermometer.

Reagents

Standard potassium chloride solution, 0.01 M.

Cell Calibration

The analyst will calibrate the EC meter following manufacturers directions. Temperature compensation will be provided for solutions deviating from 25 degrees (C). Calibration checks of the instrument with a KCl reference solution and with EPA standards will be recorded on data sheets with natural sample EC measurements.

Procedure

1. Follow manufacturer's directions for the operation of the instrument.

2. Determine temperature of sample within 0.5^{o}C. Set the solution temperature on the EC meter to convert to 25^{o}C:

3. Record measured values of EC in umhos/cm at 25^{o}C, onto custom forms (Appendix B).

The EPA standard method (120.1) for measurements of EC in water is attached.

Precision and Accuracy

Precision of water and soil EC measurements will be based on readings of sample splits. Accuracy will be based on calibration checks and values for blind field standards (EPA primary standards).

CONDUCTANCE

Method 120.1 (Specific Conductance, umhos at 25°C)

STORET NO. 00095

1. Scope and Application
   1.1 This method is applicable to drinking, surface, and saline wates, domestic and industrial wastes and acid rain (atmospheric deposition).
2. Summary of Method
   2.1 The specific conductance of a sample is measured by use of a self-contained conductivity meter, Wheatstone bridge-type, or equivalent.
   2.2 Samples are preferable analyzed at 25°C. If not, temprature corrections aremade and results reported at 25°C.
3. Comments
   3.1 Instrument must be standardized with KCl solution before daily use.
   3.2 Conductivity cell must be kept clean.
   3.3 Field measurements with comparable instruments are reliable.
   3.4 Temperature variations and corrections represent the largest source of potential error.
4. Sample Handling and Preservation
   4.1 Analyses can be performed either in the field or laboratory.
   4.2 If analysis is not completed within 24 hours of sample collection, sample should be filtered through a 0.45 micron filter and stored at 4°C. Filter and apparatus must be washed with high quality distilled water and pre-rinsed with sample before use.
5. Apparatus
   5.1 Conductivity bridge, range 1 to 1000 μmho per centimeter.
   5.2 Conductivity cell, cell constant 1.0 or micro dipping type cell with 1.0 constant. YSI #3403 or equivalent.
   5.4 Thermometer
6. Reagents
   6.1 Standard potassium chloride solutions, 0.01 M: Dissolve 0.7456 gm of pre-dried (2 hour at 105°C) KCl in distilled water and dilute to 1 liter at 25°C.
7. Cell Calibration
   7.1 The analyst should use the standard potassium chloride solution (6.1) and the table below to check the accuracy of the cell constant and conductivity bridge.

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Conductivity 0.01 m KCl

°C	Micromhos/cm
21	1305
22	1332
23	1359
24	1386
25	1413
26	1441
27	1468
28	1496

8. Procedure
   8.1 Follow the direction of the manufacturer for the operation of the instrument.
   8.2 Allow samples to come to room temperature (23 to 27°C), if possible.
   8.3 Determine the temperature of samples within 0.5°C. If the temperature of the samples is not 25°C, make temperature correction in accordance with the instruction in Section 9 to convert reading to 25°.
9. Calculation
   9.1 These temperature corrections are based on the standard KCl solution.
      9.1.1 If the temperature of the sample is below 25°C, add 2% of the reading per degree.
      9.1.2 If the temperature is above 25°C, subtract 2% of the reading per degree.
   9.2 Report results as Specific Conductance, μmhos/cm at 25°.
10. Precision and Accuracy
   10.1 Forty-one analysts in 17 laboratories analyzed six synthetic water samples containing increments of inorganic salts, with the following results:

Increment as Specific Conductance	Precision as Standard Deviation	Accuracy as Bias, %	Accuracy as Bias, umhos/cm
100	7.55	−2.02	−2.0
106	8.14	−0.76	−0.8
808	66.1	−3.63	−29.3
848	79.6	−4.54	−38.5
1640	106	−5.36	−87.9
1710	119	−5.08	−86.9

(FWPCA Method Study 1, Mineral and Physical Analyses.)

   10.2 In a single laboratory (EMSL) using surface water samples with an average conductivity of 536 μmhos/cm at 25°C, the standard deviation was ±6.

Bibliography

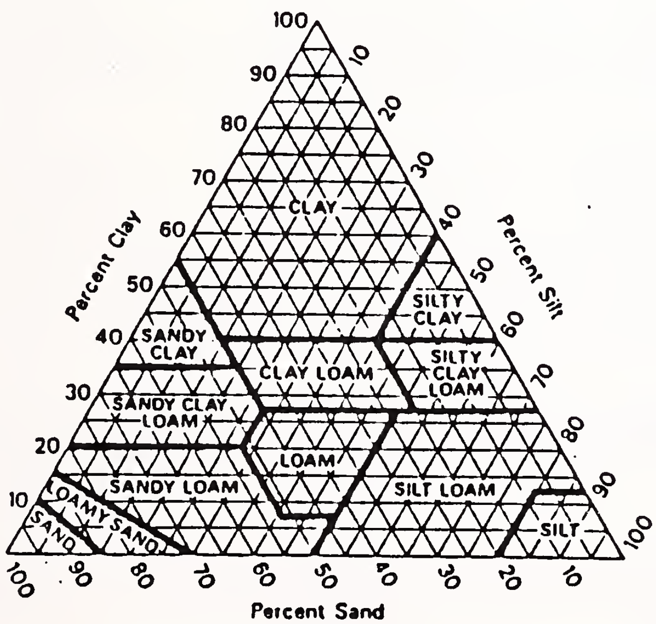
1. The procedure to be used for this determination is found in:
   Annual Book of ASTM Standards Part 31, "Water," Standard D1125-64, p. 120 (1976).
2. Standard Methods for the Examination of Water and Wastewater, 14th Edition, p. 71, Method 205 (1975).
3. Instruction Manual for YSI Model 31 Conductivity Bridge.
4. Peden, M. E., and Skowron. "Ionic Stability of Precipitation Samples," Atmospheric Environment, Vol. 12, p. 2343-2344, 1978.

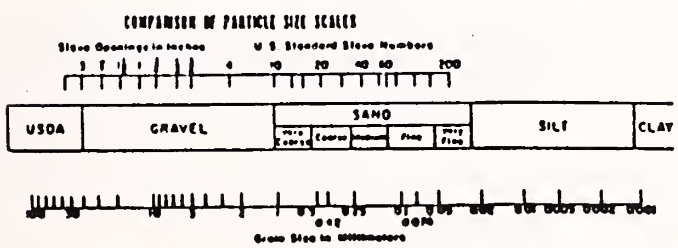
SOP 3

FIELD SOIL TEXTURE (HAND TEXTURE)

Soil texture is thought to be an important parameter influencing the chemistry, hydraulic properties, and remedial design for streambank waste deposits. Estimation of soil texture class is a component of soil horizon descriptions. Therefore, estimates of soil texture will need to be made in the field.

Soil texture class is determined by measuring or estimating the amount of sand (.05 to 2 mm size fraction), silt (.002 to .05 mm size fraction), and clay (less than .002 mm size fraction) in a soil sample. The relative amounts of each particle size are used to place the soil on a trilinear diagram (below) which is broken into texture classes.

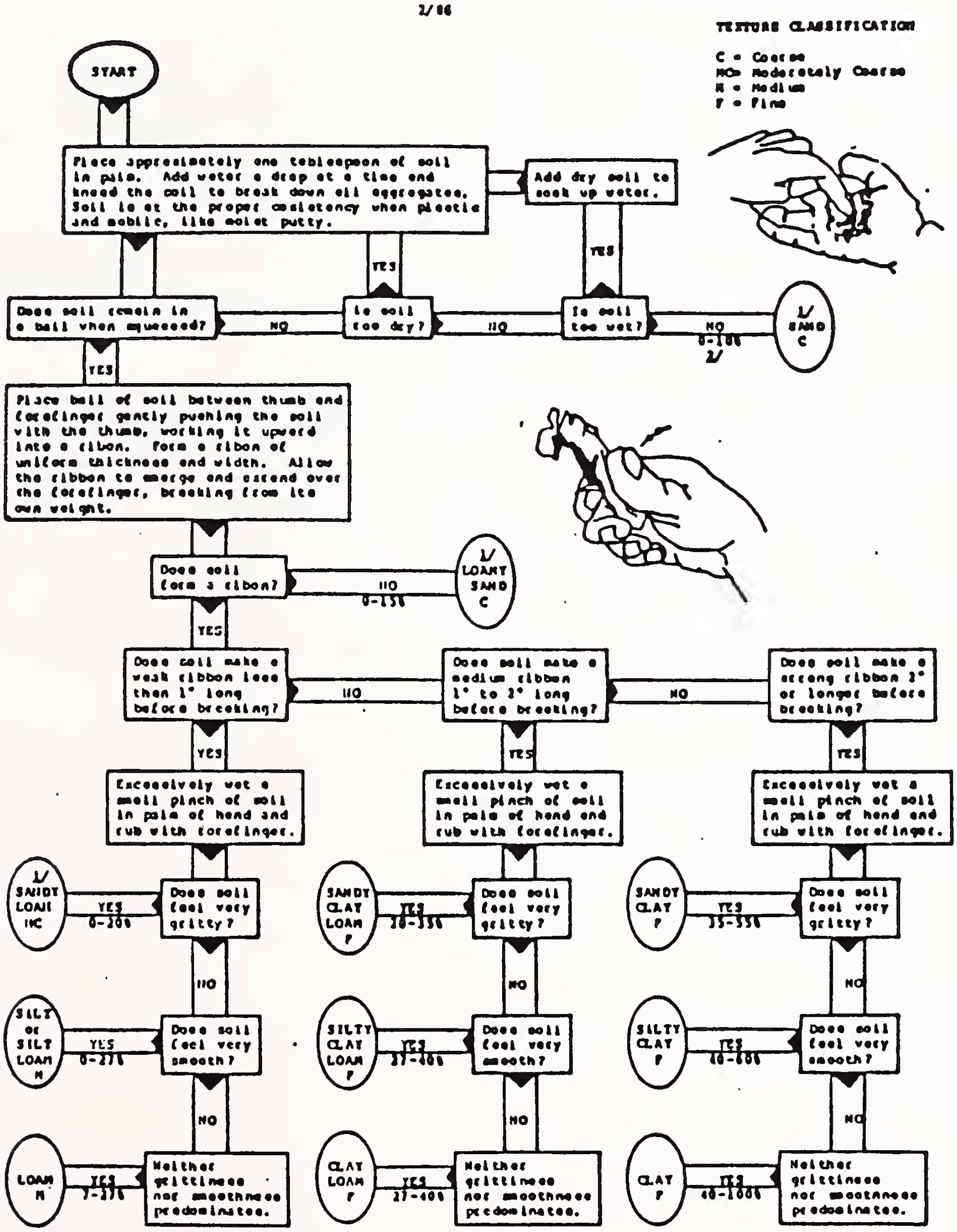




The method for determining soil texture by estimation is known as "hand texturing" or the "feel method". A description of this method is shown below. All hand textures should be performed by personnel experienced in this method. Precision and accuracy will be provided by professional judgment.

DETERMINING SOIL TEXTURE BY THE "FEEL METHOD" 3/

2/86



1/ Sand particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sand are not visible without magnification and there is a gritty feeling to a very small sample ground between teeth. Some fine sand particles may be just visible. Medium sand particles are easily visible. Examples of sand size descriptions where one size is predominant, are: very fine sand, fine sandy loam, loamy coarse sand.

2/ Clay percentage range.

3/ Modified from: Thien, Steve J.; Kansas State University, 1979 Jour. Agronomy Education.

SOP 4

SOIL SAMPLE COLLECTION

Soil samples will be collected using various coring devices as described in the technical memorandum. Samples will be collected from various depth intervals corresponding to the depth of incorporation anticipated for each plot sampled. Each sample collected will be deposited directly into a plastic tub by scraping with a plastic trowel or dumping from the coring tool. The sample will then be mixed and any clods will be broken up.

Samples will be split by mixing and dividing on a canvas sheet or by use of a mechanical sample splitter. A subsample will be set aside for XRF determination where appropriate. Sample splits for CLP submission or for use as a replicate will also be obtained as described above. A small amount of soil will be placed into two styrofoam cups for pH and SC determination. The sample will then be transferred to a 16 ounce ICHEM jar.

Between sample collection, all equipment will be cleaned thoroughly with a stiff brush and rinsed with distilled water and paper towels. The kimwipe blank will be prepared by wiping the sampling device and placing the kimwipe in a sample container.

SOP 5

SOIL MORPHOLOGY AND SITE DESCRIPTION METHOD

A description of each soil sample location will be developed. The description will consist of a generalized description of the site as well as a description of the morphological features of each soil horizon.

The site description will include an assessment of a number of generalized features including sample location, soil classification, site number, number of horizons described, soil parent material, land cover type, dominant and co-dominant species, approximate canopy cover and percent bare ground, land use, soil drainage class and permeability, evidence of erosion, slope, aspect, landscape position, landform, proximity to the Silver Bow Creek channel, depth of tailings and depth to ground water (if present). Features described will be encoded on field forms developed for this purpose. The forms are used to input data into the PEDFORM system, a proprietary database system for use with Dbase III+ so that soil morphology data can be readily linked to laboratory chemical and physical data. Numerical codes used in PEDFORM are attached.

Soil morphological features will be described for individual horizons described in each soil excavation. Horizon depths will conform to sampling depths for ease in interpretation. Horizons will be differentiated using professional judgment based on discernible differences in soil characteristics such as parent material, texture, color, structure, consistence, or other features. For each horizon, the following features will be described: depth, texture, moist and dry color (hue, value, and chroma using Munsell color notation), texture (SOP-3), structure, consistence, roots, pores, effervescence in HCl, and boundary distinctness, and shape. Horizon descriptions and horizon names will be developed in accordance with procedures established by the National Cooperative Soil Survey (SCS staff, 1975).

Table A-1. Index for parent material, vegetation, and land use codes in the PEDFORM system.

Code	Parent Material	Code	Vegetation	Code	Land Use
01	volcanic ash	01	mixed coniferous	01	commercial forest
02	loess	02	ponderosa pine	02	non-comm. forest
03	glacial outwash	03	lodgepole pine	03	forest
04	glacial till	04	spruce-fir	04	range
05	lacustrine	05	larch-fir	05	dryland crop
06	peat	06	Douglas-fir	06	irrigated crop
07	muck	07	mixed deciduous	07	irrigated hay
08	residual sandst.	08	cottonwood	08	dryland hay
09	residual shale	09	aspen	09	pasture
10	residual siltst.	10	trees	10	residential
11	residual limest.	11	dryland crop	11	urban
12	resid. crystalline	12	irrig. field crop	12	disturbed land
13	mixed alluvium	13	row crops	13	strip mine
14	alluvial	14	horticultural crop	14	mill tailings
15	colluvial	15	riparian	15	mine dump
16	soliflucate	16	mixed shortgrass	16	wildland
17	sandst. alluvium	17	mixed midgrass	17	landfill
18	shale alluvium	18	shrubs & grasses		
19	siltst. alluvium	19	halophytic		
20	crystalline alluv.	20	sedges & rushes		
21	limestone alluv.	21	perennial forage		
22	tailings	22	tame pasture		

Table A-2. Index for codes for drainage, permeability, erosion, landscape, position, and landform type in the PEDFORM system.

Code	Drainage	Code	Permeabililty	Code	Erosion
01	very poor	01	very slow	01	none
02	poor	02	slow	02	slight
03	poor to moderate	03	slow to medium	03	moderate
04	moderate	04	medium	04	severe
05	well	05	medium to rapid	05	slight-wind
06	well to excessive	06	rapid	06	moderate-wind
07	excessive	07	very rapid	07	severe-wind
08	altered, drained				
09	altered, wetted				

Table A-3. Index for landscape position and landform codes in the PEDFORM SYSTEM.

Code	Landscape Position	Code	Landform
01	crest	01	sedimentary upland
02	ridge	02	mountains
03	upper midslope	03	playa
04	midslope	04	alluvial fan
05	lower midslope	05	sand dune
06	footslope	06	glacial outwash
07	level slope	07	ground morraine
		08	alpine till
		09	terrace

10 floodplain
11 plateau
12 solifluction lobe
13 patterned ground
14 backswamp
15 landslide
16 badlands
17 disturbed land
18 talus

Table A-4. Index for texture codes in the PEDFORM system.

Code	Symbol	Texture	Code	Symbol	Texture
--- USDA TEXTURE ---			--- FAMILY TEXTURE ---		
01	s	sand	20	sndy	sandy
02	ls	loamy sand	21	colo	coarse loamy
03	lfs	loamy fine sand	22	cosi	coarse silty
04	lvfs	loamy very fine s.	23	filo	fine loamy
05	sl	sandy loam	24	fisi	fine silty
06	fsl	fine sandy loam	25	fine	fine
07	vfsl	v. fine sandy loam	26	vf	very fine
08	l	loam	27	sskl	sandy skeletal
09	sil	silt loam	28	lskl	loamy skeletal
10	scl	sandy clay loam	29	cskl	clayey skeletal
11	cl	clay loam	30	frag	fragmental
12	sicl	silty clay loam	31	ashy	ashy
13	sc	sandy clay	32	mdl	medial
14	c	clay	33	hstc	histic
15	sic	silty clay	34	fbrc	fibric
16	cos	coarse sand			
17	fs	fine sand			
18	vfs	very fine sand			
19	si	silt			

Table A-5 . Index for structure grade, size, and kind used in the PEDFORM system.

Code	Structure grade	Code	Structure kind
01	massive	01	massive
02	weak:peds barely observable in place and when disturbed peds remain	02	platy
		03	granular
03	weak to moderate	04	subangular blocky
04	moderate: peds easily observable and when disturbed most of material consists of peds.	05	angular blocky
		06	prismatic
		07	columnar
05	moderate to strong	08	wedge
06	strong: peds distinctly visible, when disturbed entire soil mass is aggregated		

Code	Size Class	Diameter of granules	Thickness of plates	Diameter of blocks	Diameter of prisms
		(mm)			
01	very fine	<1	<1	<5	<10
02	fine	1-2	1-2	5-10	10-20
03	medium	2-5	2-5	10-20	20-50
04	coarse	5-10	5-10	20-50	50-100
05	very coarse	>10	>10	>50	>100

Table A-6 . Index for soil consistence in the PEDFORM system.

Code	Dry consistence	Code	Moist consistence
01	loose	01	loose
02	soft: easily crushes to powder	02	very friable: crushes under gentle pressure
03	slightly hard: easily broken between thumb and finger	03	friable: crushes easily under moderate pressure between"THUMB and finger
04	hard:easily broken in hand	04	firm: crushes under moderate pressure between thumb and finger
05	very hard: broken in hands with difficulty	05	very firm: barely crushable between thumb and finger
06	extremely hard: cannot be broken in hands	06	extremely firm: crushes under strong pressure in hand
07	indurated	07	indurated

Code	Wet stickiness	Code	Wet plasticity
01	nonsticky: no adherence	01	nonplastic: no wire formed
02	slightly sticky: adheres to thumb and finger but comes off one cleanly	02	slightly plastic: wire forms but easily deformed
03	sticky: soil adheres and stretches before pulling apart	03	plastic: wire forms, moderate pressure required to deform
04	very sticky: soil adheres to both fingers	04	very plastic: wire forms, much pressure required to deform

Table A-7. Index for root abundance, size, and location in the PEDFORM system.

Code	Size	Code	Location
01	none	01	none
02	very fine (0.1-1mm)	02	throughout horizon
03	fine and very fine	03	between peds
04	fine (1-2mm)	04	flattened in cracks
05	medium and fine	05	flattened around rocks
06	medium (2-5mm)	06	mat at top of horizon
07	coarse and medium		
08	coarse (>5mm)		
09	fine and coarse		

Code	Abundance CLASS	Very fine	Fine	Medium	Coarse
		(NUMBER/DM**2)			
01	none				
02	trace				
03	few	<10	<10	<1	<1"
04	few to common				
05	common	10-100	10-100	1-10	1-5"
06	common to many				
07	many	>100	>100	>10	>5"

Table A-8. Index for pore abundance, size, and kind in the PEDFORM system.

Code	Size	Code	Kind
01	none	01	none
02	micro and very fine	02	irregular and tubular
03	very fine (.1-.5mm)	03	tubular
04	fine and very fine	04	tubular continuous
05	fine (.5-2mm)	05	tubular discontinuous
06	medium and fine	06	vesicular
07	medium (2-5mm)	07	vesicular and tubular
08	coarse and medium	08	interstitial voids between peds
09	coarse (>5mm)	09	interstitial voids between rocks

CODE	ABUNDANCE CLASS	VERY FINE	FINE	MEDIUM	COARSE
		----- (NUMBER/DM**2) -------			
01	none				
02	trace				
03	few	<10	<10	<1	<1"
04	few to common				
05	common	10-100	10-100	1-10	1-5"
06	common to many				
07	many	>100	>100	>10	>5

Table A-9. Index for effervescence in HCl, and horizon boundary in the PEDFORM system.

Code	Effervescence	Lower Horizon Boundary			
		Code	Distinctness	Code	Shape
01	noncalcareous	01	abrupt <1in.)	01	smooth
02	slight	02	clear (1-2.5in.)	02	wavy
03	moderate	03	gradual (2.5-5in.)	03	irregular
04	violent	04	diffuse (>5in.)	04	broken
		05	arbitrary	05	arbitrary
		06	not reached	06	not reached

SOP 6
QA/QC SAMPLES AND DOCUMENTATION

This SOP addresses the types of QA/QC samples and their method and timing of insertion into the sample matrix. These procedures are the responsibility of the DCO. QA/QC samples will not have any unique identifying codes that could enable the contract laboratory or others to identify these samples as such and thereby bias them in any way. There may be, however, obvious physical differences between blind field standards and natural samples taken at the site. The QA/QC samples will be completely identified only on the Sample Identification Matrix, which will not be sent to the contract laboratory. Samples will be identified as:

N	Natural sample
R	Replicate sample
BFS	Blind field standard (NBS)
BB	Bottle blank
CCB	Cross-contamination blank

In general, a QA/QC sample will be inserted into the sample matrix at a frequency of 1 roughly 1 in 20, or 5%. Natural soil samples will be collected with plastic sampling implements and placed in 8 ounce ICHEM jars.

Replicate samples will consist of a natural soil samples placed on canvas sheet and mixed thoroughly. The sample will be split by quartering the canvas cloth. All pH and EC measurements should be performed on both sample splits.

The cross-contamination blank will consist of a kim-wipe used as a wipe test of the sampling device after decontamination. Sample equipment decontamination will consist of brushing followed by a distilled water rinse.

The "bottle blank" soil sample will consist of a clean kim-wipe placed in an I-CHEM jar.

NBS blind field standards will be poured directly into an I-CHEM jar and submitted as the blind field standard. Approximately 5 grams of NBS standard will be used. EPA and NBS standards for water samples will be prepared in accordance with the suppliers directions.

Documentation

Complete and accurate sample documentation is essential to insure data integrity and validity. It will be the responsibility of the Document Control Officer (DCO) to assure that all QA/QC goals are met. A final check to see that all proper physical sample handling, QA/QC, and and data control protocols have been followed will help insure a usable data base.

The documents to be completed during the project may include:

1. Site / Horizon description form
2. pH and EC data form
3. XRF data form
4. ITR form
5. Chain-of-Custody Records
6. SAS Packing Lists
7. EPA sample tags
8. Rapid Carrier Forms
9. Daily Site Condition/Activity Form

Examples of each of the forms can be found in Appendix B. All documents will follow strict chain-of-custody procedures. While documents are being prepared in the field or laboratory, custody will be maintained by the DCO. After the work has been completed, photocopies of the documents will be used

as working documents. A logbook of field and laboratory work will be maintained with daily notations of work performed, accomplishments, samples collected, deviations from SOP's and justification (if any).

The purpose of documents is to contain enough information to reconstruct the sampling event without the aid of the technical crew. It will be the DCO's responsibility to assure the sufficient detail, correctness and legal integrity of the documents. All entries will be made in indelible ink and all corrections will consist of initialed and dated line-out deletions. At the completion of each sampling day, the entries will be initialed and dated by both the DCO and the original author. A line will be drawn through the remaining page to prevent unauthorized additions.

SOP 7

SAMPLE PREPARATION AND PRESERVATION

The DCO will direct all packaging and shipping procedures. Each scientist and technician involved in obtaining samples will be responsible for a specific task to ensure consistency.

Procedure

1. All soil sampling, decontamination, QA/QC samples, sample splits, and pH and SC measurement should be completed for each sample.

2. Upon filling a soil sample container, a completed EPA custody seal over the top of the container. The custody seal serves two purposes. It secures custody of the sample and it secures the lid of the container.

3. An EPA sample tag is completed by a field scientist, and is taped securely to the sample container.

4. The samples will then be placed into a cooler labeled "SOIL SAMPLES" or "WATER SAMPLE", with the site identification and date also written on the cooler top. Since soil samples will be in glass ICHEM jars, they will be packed with vermiculite to prevent breakage. The cooler will be packed full, so there is no empty space for the contents to move about.

5. When the cooler is full, or when the sample collection is complete, a Chain-of-Custody form, Inorganic Traffic Report (ITR) (for Routine Analytical Services - RAS), or Special Analytical Service (SAS) packing list, and sample identification matrix form will be

completed. A prenumbered airbill will be assigned to that cooler. Examples of all forms are in Appendix B.

6. The DCO will double check the forms to assure those samples mentioned on the COC, ITR and SAS are all present and accounted for in the cooler. He/she will document this on the ITR, SAS Packing List and Sample ID Matrix.

7. The cooler will be clearly marked "FRAGILE/THIS SIDE UP" on all four sides and the top as appropriate.

8. The DCO will then place the proper COC, ITR and SAS Packing Lists in a Ziploc bag, taped to the inside roof of the cooler.

9. The DCO or scientist will then close the cooler and affix the airbill to the top of the cooler.

10. The DCO or field scientist will then seal the cooler and place the appropriate COC seals (one in front and one in back), signed and dated, on the cooler.

11. The field scientist will then place fiberglass tape over the custody seals and around the cooler, making sure everything is secure.

12. The cooler will be labeled as to type of samples and date of sampling, with a large felt-type pen.

13. The cooler(s) will then be transported to a secure storage facility, where they can be kept under custody until they are shipped.

SOP 8

X-RAY FLUORESCENCE SPECTROMETER (XRF) USE AND CALIBRATION

The chemical characterization of soil samples in the field will be determined by the field portable x-ray fluorescence (XRF) spectrometer ATX-100 instrument manufactured by Aurora Tech, Inc, 331 Rio Grande Street, Salt Lake City, Utah. The instrument uses low level self-contained and shielded radioactive sources that produce spectral peaks whose position (energy level) is specific to an individual element and whose peak height or area which is indicative of the concentration of that element within the area exposed to the source. Two sources are proposed to be used, cadmium-109 (15 millicuries) and iron-55 placed by the manufacturer. These sources will allow semi-quantitative determination of the copper, zinc, arsenic, iron, manganese and lead concentrations.

The detection limit for each parameter is a function of source strength, geometry/particle size, counting time, and the concentration of other elements. Since the source strength and instrument geometry are constants, the detection limit is dependent on geometry/particle size, counting time, and concentration. It has been demonstrated that 80 mesh particle size dominantly composed of a siliceous or calcareous skeletal matrix will give analytical results within 20 percent. The larger the particle size, the larger the error. In a soil matrix the larger the particles, the larger the error. A rock made up of fine-grained minerals, however, will essentially have the same precision and accuracy as a finely ground sample.

The XRF spectrometer will be calibrated at Aurora Tech using several samples of waste material that were collected and analyzed as part of the STARS Phase I activities. These same samples will be used to ensure calibration of the instrument at each collection site during field activities.

This field calibration will be based on the factory calibration. Peak area counts and index values for the field calibration will be compared to the initial calibration and levels of Cu, Zn, Fe, Mn, Pb, As, and Cd will be recorded in the field. Data for all spectral lines will be uploaded onto a compact battery-powered microcomputer in the field. A backup hard copy of the data will be maintained to protect against inadvertent data loss or equipment malfunction.

Spectral overlap of As/Pb peaks will be resolved using matrix correction of secondary peaks.

APPENDIX B

STANDARD FORMS

SOIL pH AND EC DATA FORM

SITE DESCRIPTION FORM

HORIZON DESCRIPTION FORM

DAILY SITE CONDITION/ACTIVITY FORM

INORGANIC TRAFFIC REPORT FORM

CHAIN-OF-CUSTODY RECORD

SAS PACKING LIST

EPA TAG

CUSTODY SEALS

SAMPLE IDENTIFICATION MATRIX

RAPID CARRIER FORM

Schafer & Associates
P.O. Box 6186
Bozeman, MT 59715
(406) 587-3478

Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

WATER pH AND SC DATA FORM

JOB SITE ID :
PAGE NO.:
FIELD TEAM MEMBERS :

DATE :
COMMENTS:

ENTRY NUMBER	MATRIX TYPE	STATION LOCATION	SAMPLE TYPE	TAG NUMBER	MEASURED pH	SC mmhos/cm
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						

MATRIX : L = LYSIMETER, IR = IRRIGATION/RUNOFF

LOCATION: ie. RF15 = RAMSAY FLATS SAMPLE 15. THESE SHOULD MATCH THE STATION LOCATION ON THE SAMPLE ID MATRIX FORM

TYPE : N = NATURAL SAMPLE, R = REPLICATE, CCB = CROSS-CONTAMINATION BLANK, BB = BOTTLE BLANK, BFS = BLIND FIELD STANDARD

Schafer & Associates
P.O. Box 6186
Bozeman, MT 59715
(406) 587-3478

Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

SITE DESCRIPTION

PEDFORM Coding Form - Soil Profile Description Site Information

SOIL SERIES: SITE NUMBER: COUNTY:

LOCATION:
CLASSIFICATION:
DATE SAMPLED: ELEVATION: (FT or M) PRECIPITATION: (IN or MM)

MATERIAL

01 volcanic ash
02 loess
03 glacial outwash
04 glacial till
05 lacustrine
06 peat
07 muck
08 residual sandstone
09 residual shale
10 residual siltstone
11 residual limestone
12 residual crystalline
13 mixed alluvium
14 alluvium
15 colluvium
16 soliflucate
17 sandstone alluvium
18 shale alluvium
19 siltstone alluvium
20 crytalline alluvium
21 limestone alluvium
22 tailings

VEGETATION

01 mixed coniferous
02 ponderosa pine
03 lodgepole pine
04 spruce-fir
05 larch-fir
06 Douglas fir
07 mixed deciduous
08 cottonwood
09 aspen
10 trees
11 dryland crop
12 irrigated field crop
13 row crops
14 horticultural crop
15 riparian
16 mixed shortgrass
17 mixed midgrass
18 shrubs and grasses
19 halophytic
20 sedges and rushes
21 perennial forage
22 tame pasture
23 bare ground
24 dead litter

LAND USE

01 commercial forest
02 non-commercial forest
03 forest
04 range
05 dryland crop
06 irrigated crop
07 irrigated hay
08 dryland hay
09 pasture
10 residential
11 urban
12 disturbed land
13 strip mine
14 mill tailings
15 mine dump
16 wildland
17 landfill
18 subirrigated hay

DRAINAGE

01 very poor
02 poor
03 somewhat poor
04 moderately well
05 well
06 somewhat excessive
07 excessive
08 altered, drained
09 altered, wetted

PERMEABILITY

01 very slow
02 slow
03 moderately slow
04 moderate
05 moderately rapid
06 rapid
07 very rapid

EROSION

01 none
02 slight
03 moderate
04 severe
05 slight - wind
06 moderate - wind
07 severe - wind

SLOPE: deg, % ASPECT: SOIL TEMP (50 cm): F C

LANDSCAPE POSITION

01 crest
02 ridge
03 upper midslope
04 midslope
05 lower midslope
06 footslope
07 level slope

LANDFORM

01 sed. upland
02 mountains
03 playa
04 allvl. fan
05 sand dune
06 outwash
07 ground morrain
08 alpine till
09 terrace
10 floodplain
11 plateau
12 mudflow
13 patterned ground
14 backswamp
15 landslide
16 badlands
17 disturbed land
18 talus

NUMBER HORIZONS: ---------

COMMENTS:

Schafer & Associates
P.O. Box 6186
Bozeman, MT 59715
(406) 587-3478

Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

HORIZON DESCRIPTION

PEDFORM Coding Form - Soil Profile Description Horizon Data

:::

SITE NUMBER: HORIZON NUMBER:

HORIZON DESIGNATION: START DEPTH: (cm) END DEPTH: (cm)

MOIST COLOR: DRY COLOR: COARSE FRAGMENTS: (%)

TEXTURE		STRUCTURE			CONSISTENCE			
		GRADE	SIZE	KIND	DRY	MOIST	STICKY	PLASTIC
01 s	17 fs	01 massive	01 massive	01 massive	01 loose	01 loose	01 non	01 non
02 ls	18 vfs	02 weak	02 v. fine	02 platy	02 soft	02 v. fri.	02 slt.	02 slt.
03 lfs	19 si	03 wk-mod.	03 fine	03 gran	03 s.hard	03 fr.	03 sticky	03 plastic
04 lvfs	20 sndy	04 mod.	04 med.	04 sbk	04 hard	04 firm	04 v.stky	04 v.plstc
05 sl	21 co-lo	05 mod-strg	05 coarse	05 abk	05 v.hard	05 v.firm		
06 fsl	22 co-si	06 strong	06v.coarse	06 prism	06 ex.hrd	06 ex.firm		
07 vfsl	23 fi-lo			07 clmnr.	07 indurated			
08 l	24 fi-si			08 wedge				
09 sil	25 fine							
10 scl	26 very fine							
11 cl	27 s. skl.							
12 sicl	28 l. skl.							
13 sc	29 c. skl.							
14 c	30 frag.							
15 sic	31 ashy							
16 cos	32 medial							

ROOTS			PORES		
NUMBER	SIZE	LOCATION	NUMBER	SIZE	KIND
01 none	01 none	01 none	01 none	01 none	01 none
02 trace	02 fine	02 thru-out	02 trace	02 v.fine	02 irreg.
03 few	03 f/vf	03 between peds	03 few	03 f/vf	03 tubular
04 few-com	04 fine	04 cracks	04 few-com	04 fine	04 tub. continuous
05 common	05 med/f	05 near rocks	05 common	05 med/f	05 tub. discont.
06 com-mny	06 medium	06 mat at top	06 com-mny	06 medium	06 vesicular
07 many	07 co/med		07 many	07 co/med	07 tub. & tubular
	08 coarse			08 coarse	08 interstitial between rocks

pH: ---------

EFFERVESCENCE	BOUNDARY	
	DISTINCTNESS	SHAPE
01 non calcareous	01 abrupt (<1")	01 smooth
02 slight	02 clear (1-2.5")	02 wavy
03 moderate	03 gradual (2.5-5")	03 irregular
04 violent	04 diffuse (>5")	04 broken
	05 arbitrary	
	06 not reached	

COMMENTS:

Schafer & Associates
P.O. Box 6186
Bozeman, MT 59715
(406) 587-3478

Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

DAILY SITE CONDITIONS / WORK DESCRIPTION FORM

SITE / PERSONNEL DATA:
::

SITE ID : ____________________ PAGE : ____ OF ____

ARRIVAL TIME : ____________ DEPARTURE TIME : ____________

LOCATION : ____________________ DATE: / /

PERSONNEL: ____

WEATHER:
::

WIND SPEED : ________________ WIND DIRECTION: ______________

PRECIPITATION TYPE: ____________ AMOUNT : ______________

CLOUD COVER : ________________ TEMPERATURE : ______________

CREEK LEVEL / APPEARANCE : ____________________________________

COMMENTS:
::

WORK ACCOMPLISHED : ____

____

____

DEVIATIONS FROM SOP´S : _______________________________________

____

____

CONTACTS : ____

____

GENERAL COMMENTS : ____

____

____

____

U.S. ENVIRONMENTAL PROTECTION AGENCY HWI Sample Management Office
P.O. Box 818 Alexandria, VA 22313 — 703/557-2490 · FTS/557-2490

INORGANICS TRAFFIC REPORT

Sample Number
MHA 434

① Case Number: ____
Sample Site Name/Code: ____

② SAMPLE CONCENTRATION
(Check One)
____ Low Concentration
____ Medium Concentration

③ SAMPLE MATRIX
(Check One)
____ Water
____ Soil/Sediment

④ Ship To:

Attn: ____

Transfer
Ship To:

⑤ Sampling Office: ____
Sampling Personnel:
(Name) ____
(Phone) ____
Sampling Date.
(Begin) ____ (End) ____

⑥ Shipping Information:
Name Of Carrier:
____
Date Shipped. ____
Airbill Number: ____

⑦ Sample Description:
(Check One)
____ Surface Water
____ Ground Water
____ Leachate
____ Mixed Media
____ Solids
____ Other ____
(specify)
MATCHES ORGANIC SAMPLE NO ____

⑧ Mark Volume Level
On Sample Bottle
Check Analysis required
__ Task 1 & 2
__ Task 3 Ammonia
Sulfide
Cyanide

MHA 434 - Task 1 & 2
MHA 434 - Task 1 & 2
MHA 434 - Task 3
MHA 434 - Task 3
MHA 434 - Task 3
MHA 434 - Task 3
MHA 434 - Task 3

SMO COPY

INORGANIC TRAFFIC REPORT

SILVERBOW CREEK, MT RI/FS

ENVIRONMENTAL PROTECTION AGENCY
Environmental Services Division

REGION 8
1860 Lincoln Street
Denver, Colorado 80295

CHAIN OF CUSTODY RECORD

PROJ NO	PROJECT NAME					NO OF CON-TAINERS							REMARKS
SAMPLERS (Signature)													
STAT NO	DATE	TIME	COMP	GRAB	STATION LOCATION								

Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Relinquished by: (Signature)	Date / Time	Received by: (Signature)	Relinquished by: (Signature)	Date / Time	Received by: (Signature)
Relinquished by: (Signature)	Date / Time	Received for Laboratory by: (Signature)	Date / Time	Remarks	

8-0584

CHAIN OF CUSTODY RECORD

SILVERBOW CREEK, MT RI/FS

U.S. ENVIRONMENTAL PROTECTION AGENCY
CLP Sample Management Office
P.O. Box 818 - Alexandria, Virginia 22313
Phone: 703/557-2490 - FTS/557-2490

SAS Number

SPECIAL ANALYTICAL SERVICE
PACKING LIST

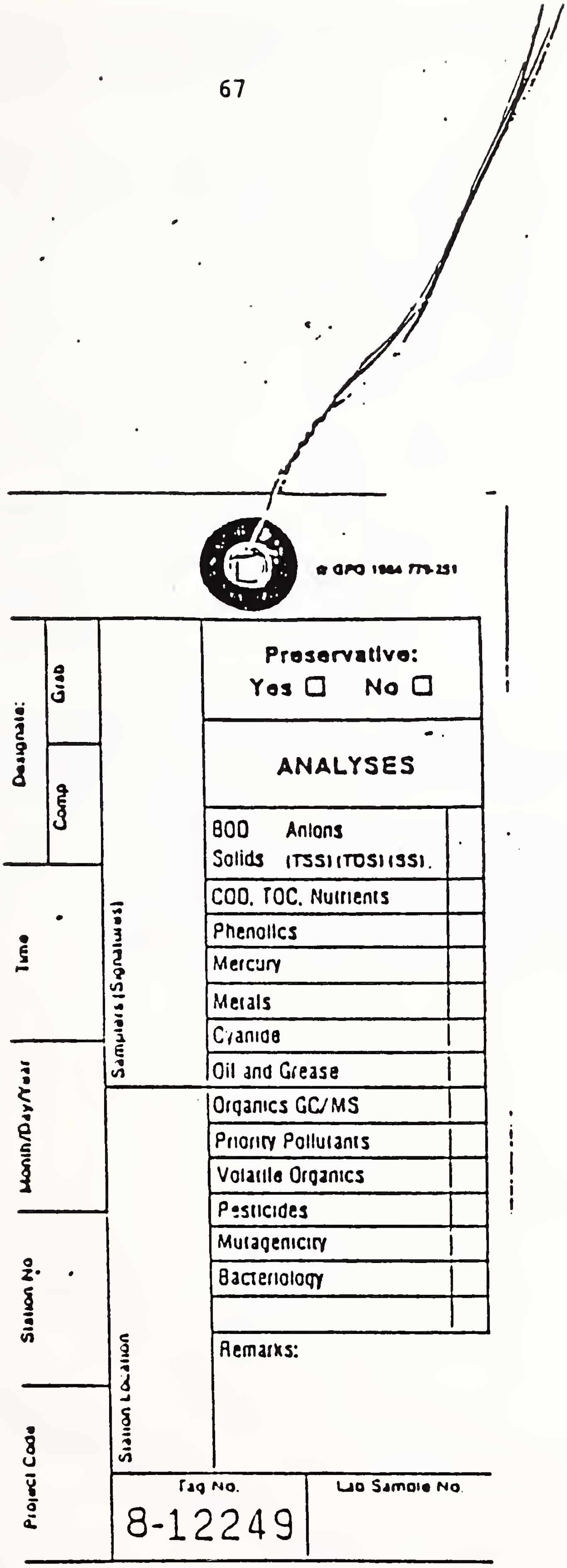
Sampling Office:	Sampling Date(s):	Ship To:	For Lab Use Only
Sampling Contact:	Date Shipped:		Date Samples Rec'd:
(name)	Site Name/Code:		Received By:
(phone)		Attn:	

Sample Numbers	Sample Description- I.e., Analysis, Matrix, Concentration	Sample Condition on Receipt at Lab
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		

For Lab Use Only

White - SMO Copy, Yellow - Region Copy; Pink - Lab Copy for return to SMO, Green Lab Copy

SAS PACKING LIST


☆ GPO 1984 779-251

Project Code | Station No. | Month/Day/Year | Time | Designate: Comp | Grab

Station Location

Samplers (Signatures)

Preservative: Yes ☐ No ☐

ANALYSES

BOD Anions Solids (TSS) (TDS) (SS)	
COD, TOC, Nutrients	
Phenolics	
Mercury	
Metals	
Cyanide	
Oil and Grease	
Organics GC/MS	
Priority Pollutants	
Volatile Organics	
Pesticides	
Mutagenicity	
Bacteriology	

Remarks:

Tag No.	Lab Sample No.
8-12249	

EPA SAMPLE TAG

SILVERBOW CREEK, MT RI/FS

FEDERAL EXPRESS

USE THIS AIRBILL FOR DOMESTIC SHIPMENTS WITHIN THE CONTINENTAL U.S.A., ALASKA AND HAWAII.
COMPLETE PURPLE AREAS. FOR ASSISTANCE, CALL 800 238-5355 TOLL FREE.
SEE BACK OF FORM SET FOR COMPLETE PREPARATION INSTRUCTIONS.

SENDER'S FEDERAL EXPRESS ACCOUNT NUMBER: 1000-5628-1

DATE: 5/12/87

60588

1 From (Your Name): WILLIAM SCHAFER
Your Phone Number (Very Important): (406) 587 3472
Company: ~~H & H HILL~~ SCHAFER & ASSOC.
Department/Floor No.
Street Address: ~~995 S. SYRACUSE~~ 611 N WALLACE #1B
City: ~~ENGLEWOOD~~ BOZEMAN, MT
State: ~~CO~~

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Total 1	Total	Total	

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OFFICIAL SAMPLE SEAL

SAMPLE NO.
SIGNATURE
PRINT NAME AND TITLE (Inspector, Analyst or Technician)
DATE
SEAL BROKEN BY
DATE
EPA FORM 7500-2 (R7-75)

CH2M HILL
SAMPLE IDENTIFICATION MATRIX

BY: ____________ DATE ____________ PROJECT NO. ____________

SITE ____________

ACTIVITY ____________

CASE/SAS NUMBER ____________

INSTRUCTIONS

- ONE SI MATRIX PER COOLER/COC
- SEND SI MATRIX WITH SAMPLE CODE OBSCURED TO LAB
- SEND SI MATRIX TO SMO
- ANALYSIS CODES COMPLETED BY SAMPLERS IN ACCORDANCE WITH CLP REQUEST
- ONE CONTAINER AND TAG NUMBER PER LINE

NOTES ____________

STATION LOCATION	SAMPLE TYPE	SAMPLE CODE	ANALYSIS CODE	SMO NUMBER	SAMPLE TAG NUMBER	BOTTLE SIZE & TYPE	QC BOTTLE LOT NUMBER	DATE/TIME SAMPLED 19__	PRESERVATION CODE	COMMENTS

CLP LABORATORY ____________ PHONE ____________

CHAIN OF CUSTODY NUMBER ____________

DATE SHIPPED/CARRIER ____________

AIRBILL NUMBER ____________

ANALYSIS CODES ____________

SAMPLE TYPES: GW = GROUND WATER
SW = SURFACE WATER
SE = SEDIMENT
SC = SOIL CORE
-G = GRAB SAMPLE
-C = COMPOSITE
-F = FILTERED
-U = UNFILTERED
EXAMPLE: SWG-F = FILTERED SURFACE WATER GRAB SAMPLE

SMO NUMBER: ITR NUMBER
[illegible] NUMBER
SAS PACKING LIST NUMBER
[illegible] NUMBER

SAMPLE CODES: N = NATURAL SAMPLE
D = DUPLICATE
RB = RINSATE BLANK
BFS = BLIND FIELD STANDARD
([illegible] WATER OR SOIL)
FS = FIELD SPIKE
SB = SOIL BLANK
WB = WATER BLANK
BB = BOTTLE BLANK

BOTTLE SIZE & TYPE: 1L AGB = 1 LITER AMBER GLASS BOTTLE
[illegible] AGB = [illegible] OZ. AMBER GLASS BOTTLE
40 GV = 40 ML GLASS VIAL
1 LPB = 1 LITER POLYETHYLENE BOTTLE
120 WMGV = 120 ML WIDE MOUTH GLASS VIAL
16 WMGJ = 16 OZ WIDE MOUTH GLASS JAR
8 WMGJ = 8 OZ WIDE MOUTH GLASS JAR
32 WMGJ = 32 OZ WIDE MOUTH GLASS JAR
4 WMGJ = 4 OZ WIDE MOUTH GLASS JAR

CH2M HILL DENVER [illegible]
SAMPLE MANAGEMENT OFFICE
[illegible]
FEDERAL EXPRESS ACCT. NO. [illegible]

PRESERVATIVE CODE: NP = UNPRESERVED
[illegible] = REFRIGERATED AT 4°C OR LOWER
[illegible] = REFRIGERATED AT 4°C OR LOWER AND
HNO_3, NITRIC ACID ADDITION TO pH < 2
[illegible] = REFRIGERATED AT 4°C OR LOWER AND
NaOH SODIUM HYDROXIDE ADDITION TO pH > 12

APPENDIX C

DESCRIPTION OF DEEP INCORPORATION METHODS

MECHANICAL DEEP INCORPORATION (ALBERTA MULTI-LEVEL PLOW)

MECHANICAL DEEP INCORPORATION (BOMAG: ROTARY MIXING)

PRESSURE SLURRY INJECTION (GKN WOODBINE METHOD)

MECHANICAL DEEP-INCORPORATION: PLOWS

The Engineering branch of Alberta Agriculture has developed a series of prototype deep-plows for improvement of sodic glacial till soils in north-central Alberta. Plows mix soils to a depth of 18 to 24 inches. Details on the design and operation of the most recent plow design, a three-layer plow is contained in:

Kienholz, J.C. 1976. Development of a three-layer solonetzic soil reclamation plow. Canadian Society of Agricultural Engineers. Halifax, N.S. July 4, 1976.

C S A E

S C G R

Paper No. 76-313

DEVELOPMENT OF A THREE-LAYER SOLONETZIC SOIL RECLAMATION PLOW

J. C. Kienholz
Associate Member CSAE
Engineering Field Services Branch
Alberta Agriculture
Edmonton, Alberta

For presentation at the 1976 Annual Meeting
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
July 4 to 8, Halifax, N.S.

Abstract

Soil dynamics of tillage implements along with field observations of various plows were utilized in the design of a three-layer solonetzic soil reclamation plow. The plow was designed to plow to a depth of 76 cm. The main points of consideration were scouring, draft, stability and soil placement. A combination of cylindrical and exponential curves defined the shape of the moldboards. Share approach angles of 20° and 30° were used for the digging bottom and loose soil bottoms, respectively. An air-hardening abrasion-resistant alloy steel was used for the shares, moldboards and landsides. A modified grader blade was utilized to remove the top soil. The grader blade, loose soil bottom and digger bottom were arranged so as to leave the plowed soil with a mixture of Ap and Csk horizons overlying the Bnt and Csk horizons. Stability was achieved utilizing a unique arrangement of three wheels and a single landside.

INTRODUCTION

Crop yields have been substantially reduced in the solonetzic areas of the prairie provinces. This is mainly due to the impermeability of the Bnt horizon to both roots and water. In Alberta there are about 12 million acres of these soils of which 1.2 million are reclaimable.[1]

A literature search has shown that plowing is the most efficient means of reclaiming these soils. Plows that have been used, however, are either not suitable to the prairie conditions or are not available. As a result of these findings it was decided to develop a plow capable of reclaiming these soils.[2]

To reclaim these soils the plow had to leave a mixture of the Ap and Csk horizons overlying a mixture of the Bnt and Csk horizons. The plow had to be capable of plowing to a maximum depth of 76 cm to obtain the Csk horizon. Because of the variability and possible stickiness of these soils the plow had to be designed for maximum scouring. The plow also had to have a moderate draft which was within the capabilities of moderate-sized 4-wheel drive tractors.

A BRIEF DESCRIPTION OF THE SOIL

The term "solonetz" is of Russian origin. It describes a saline and/or alkaline soil containing a significant portion of sodium salts that deflocculate the soil.[3]

The most restricting problem to plant growth with these soils is the impermeability of the Bnt horizon to both roots and water.[4] Deep plowing was found to achieve the most permanent and economical means of reclaiming these soils.[5] This fractures the Bnt horizon and mixes the calcium rich Csk horizon with the high sodium Bnt horizon. It is desirable to leave a mixture of Ap and Csk horizons overlying a mixture of Bnt and Csk horizons. This is achieved with a three-layer plow.

OPERATION OF THE THREE-LAYER PLOW

The operation of the plow can best be described by discussing the operating of each bottom starting with the front bottom.

The front bottom scrapes the top soil into the previous furrow (Figures 1 and 3).

The second bottom is offset to the right of the other bottoms (Figure 3). It runs in the previous furrow, removing a 2-15 cm slice of Csk horizon from the bottom of the furrow (Figure 1). This slice of Csk horizon remains relatively intact as it slides up the moldboard, and is used to carry with it loose top soil deposited in the furrow by the front bottom. This mixture of Ap and Csk horizon is, therefore, effectively deposited on the mixture of Bnt and Csk horizons.

The third bottom follows the first bottom (Figure 3), turning the hard columnar Bnt horizon along with some Csk horizon into the furrow just cleaned out by the second bottom (Figure 2). This arrangement of bottoms leaves the Ap and Csk horizons overlying a mixture of Bnt and Csk horizons.

THEORY OF PLOW BOTTOM DESIGN

The plow bottom transfers energy to the soil. The amount of energy transferred will determine to what degree the soil is fractured and, therefore, to a large degree the amount of power that is required to pull the plow.

The way this energy is transferred will determine the amount of pressure on the various areas of the share and moldboard. It will also influence the down and side forces that must be absorbed by the tractor through the hitch.

The moldboard is that part of the bottom which lifts and turns the soil. The type of moldboard will determine the way in which the soil is turned. Generally, however, the soil is turned as indicated in Figure 7.[6]

The cross-section of the furrow slice A, B, C, D is first rotated about point C to the vertical position C, E, F, G. It is then rotated about E to position E, H, I, J.

In order that the furrow slice remains in the turned position, the centre of gravity (C of G) must be to the left of a vertical line through point E as shown in Figure 7.

This will occur when the width of cut exceeds 1.27 times the depth of cut.[7]

By increasing the speed above 4.8 km/h, the bottom will cause the furrow slice to follow a trejectory similar to that in Figure 8.[8]

The height H of the trejectory will increase by approximately 5 cm for every 1.6 km/h over 4.8 km/h.[9]

Figure 7 shows the turning of the soil using a helical moldboard. This type of moldboard requires the least amount of energy to turn a furrow. The soil is rotated about the longitudinal axis only.[10]

At the other end of the scale is the cylindrical moldboard. This moldboard bends the soil severely about all axes. Thus the energy requirements are high for this moldboard.[11] Other moldboards may be parabolic, elliptical, hyperbolic, involute or various combinations of these. These moldboard curves or combinations of them can be utilized to give a complete range of operating characteristics between that of the helical and that of the cylindrical moldboards.

Scouring

Scouring occurs when soil-metal friction is less than soil-soil friction. It is affected by the following factors as found by Payne and Fontaine.[12]

1. The coefficient of soil-metal friction.
2. The coefficient of soil-soil friction.
3. The angle of approach of the tool.
4. The soil cohesion.
5. The soil adhesion.

The following discussion of scouring will be confined to the clay soils, since these are more characteristic of the solonetz soils.

The coefficient of soil-metal friction is influenced by the polish of the steel, the distance the soil slides on the steel and the normal force applied.[13] Polish is mainly a function of hardness, which is determined by the carbon content of the steel.

Soehni found that the coefficient of friction increases as length of the sliding surface increases.[14] This, he believes, is due to the smearing of soil, which is actually the increase in the actual soil-metal contact area for a given block of soil. The greatest change in the coefficient of friction he observed involved dry soil.

Vetrov has shown that the coefficient of soil-metal friction decreases for increases in the normal pressure up to 676 kPa.[15]

Soil moisture affects the soil-metal friction as indicated in Figure 9.

At the Soil Mechanics Lab at Harvard it was found that electro-osmosis drew moisture to the moldboard, thus reducing the draft.[16] This would effectively reduce the draft forces.

Soil-soil friction and shear strength are about the same for a normal, mildly structured soil. For this reason there has been very little research done on soil-soil friction as it is applied to tillage machinery. It has been found though that soil-soil friction decreases with increases in soil moisture.[17]

To permit uniform scouring on the moldboard, there must be a constant pressure between the moldboard and the soil. This can be

achieved with an exponentially curved moldboard which will bend the soil into an ever tighter circle as it travels up the moldboard.

Cohesion in solonetz soils is extremely high due to deflocculation caused by the high levels of sodium salts. It is important to consider this when designing the lower part of the moldboard. It will mean that this part of the moldboard will have a very slow rate of change of curve. Failure to consider this will result in extremely high pressures on the lower part of the moldboard with a resultant high rate of wear. Because of the cohesion creating high pressures on the lower part of the moldboard, scouring is not a problem on that area of the moldboard.

Adhesion is the mechanism that causes soil to stick to a surface. It is due almost entirely to the surface tensions of the moisture film. Wetability is a measure of the degree to which water will adhere to the surface of a metal. On a highly wetable surface the water will spread over the surface in a thin film, whereas on the nonwetable surface the water will draw together in droplets. The wetting angles as shown in Figure 10 are a measure of the wetability of a material.

An example of wetting angles of a soil solution from sumpter clay on various metals are as follows:[18]

- cast iron 65.5
- stainless steel 81.5
- plow steel 76.5

The above example indicates that stainless steel has the higher wetting angle and, therefore, less adhesion. With less adhesion, better scouring and lower friction can be achieved. Therefore, materials with high wetting angles should be used for good scouring.

Shares

The plow share is that part of the bottom which cuts the soil and initiates the flow of the soil up the moldboard. The main considerations in the design of the share are draft and wear.

Draft of the share is influenced mainly by the angle of approach. The chart in Figure 11 shows the result of Kawamura's studies for draft of inclined tools.[19] This chart indicates that an angle delta (δ) of 20 degrees is an efficient approach angle.

The angle of the share to the landside will determine to a large extent the degree to which the soil will be initially lifted. The smaller the angle the lower the lift. The smaller angles are generally used for higher speeds. An angle of 45 degrees is a standard angle for speeds up to 4.8 km/h. The larger angles are used where it is desired to lift the soil or when transmitting high energies to the furrow slice.

Materials for shares must be tough, wear-resistant and have a high wetting angle. To be efficient they should also maintain a sharp cutting edge. The common steel for shares is a high carbon steel (1090). Alloyed steel may also be used if the increased performance warrants the additional cost.

The share cutting edge should be kept sharp to maintain penetration, reduce draft and minimize compaction under the share. This is accomplished by:

- using the thinnest share possible without encountering undo breakage.

- case hardening the top surface of a lower carbon steel.

- applying a thin, smooth layer of hard facing to the topside of the share.

Gavrilov and Koruschkin showed that the draft of a dull share was up to 30 percent higher than that of a sharp share.[20] This stresses the importance of selecting and applying the proper steel and/or hard facing treatment to maintain a sharp share.

PLOW DESIGN

The plow was designed in two main stages. The bottoms were designed first; then to hold these bottoms a chassis was designed.

Design Criteria for the Three Bottoms

Design criteria for the bottoms was extracted from the specifications of the soil profile and the theories previously outlined in this paper.

Criteria for the front bottom was based on the maximum depth of top soil, 16 cm, and the minimum width of cut of the rear bottom. Because the bottom was required to move the topsoil to the side, a grader blade, which was readily available, was used. Adjustment

both fore and aft, and vertically was provided by means of a clamp which held the bottom to the frame.

Criteria for the second bottom was based on the requirement of having up to 16 cm of Csk horizon removed from the bottom of the furrow and carried along with the top soil to the top of the previous furrow slice. The width of cut was the same as the front bottom. The angle of the share was set at 60 degrees to the landside to lift the soil. An elliptical curve was used at the tip of the moldboard which was blended into a cylindrical curve at the leading edge of the share. This arrangement of curves minimized the fracturing of the slice of Csk horizon that was to carry the Ap horizon to the top of the previous furrow. The approach angle of the share was set at 30 degrees so as to lift the soil. This was later found to be partially responsible for the high draft of the second bottom. A 20 degree angle of approach would have been better. Adjustment was provided by means of a clamp which held the bottom to the frame.

Criteria for the third bottom was based on the maximum depth of cut, 45 cm, which also set the minimum width of cut at 60 cm. This is the minimum width of cut for the depth that will stay turned. A parabolic curve was used at the wing tip which was blended into a cylindrical curve at the leading edge of the share. The approach angle of the share was set at 20 degrees; the optimum angle as discussed previously in this paper. This combination imparted good scouring and light draft. This bottom was also attached by means of a clamp to accommodate the experimental nature of the plow.

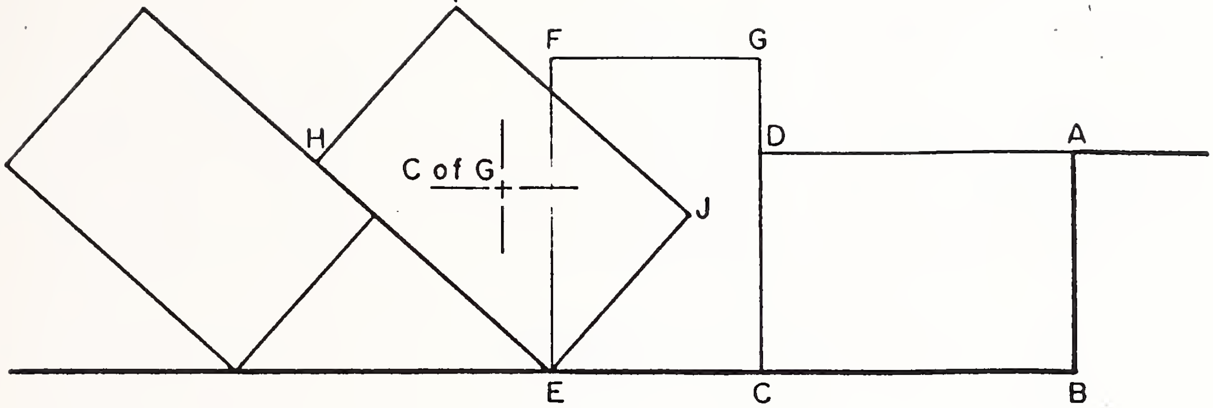


FIGURE 7

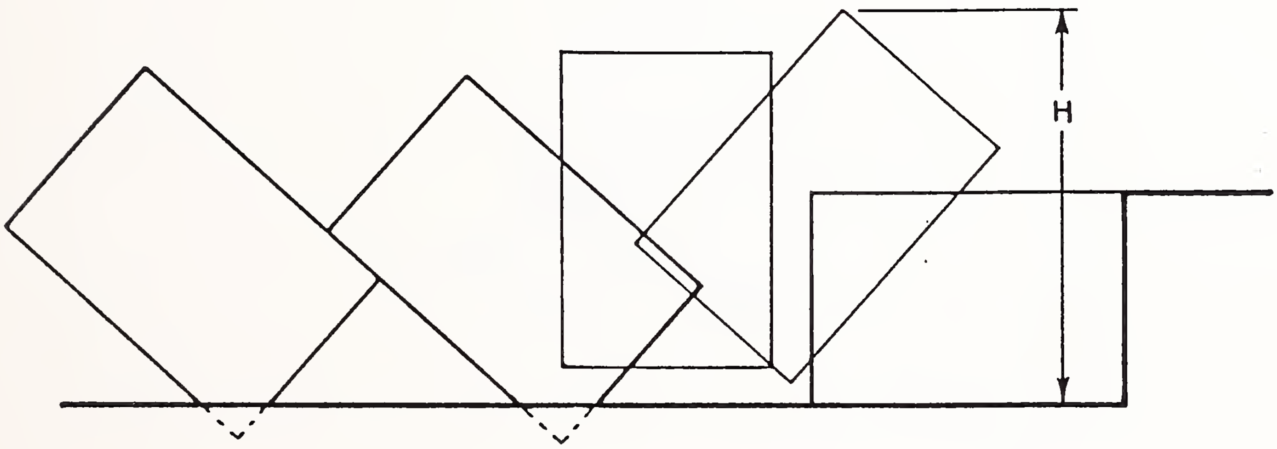


FIGURE 8

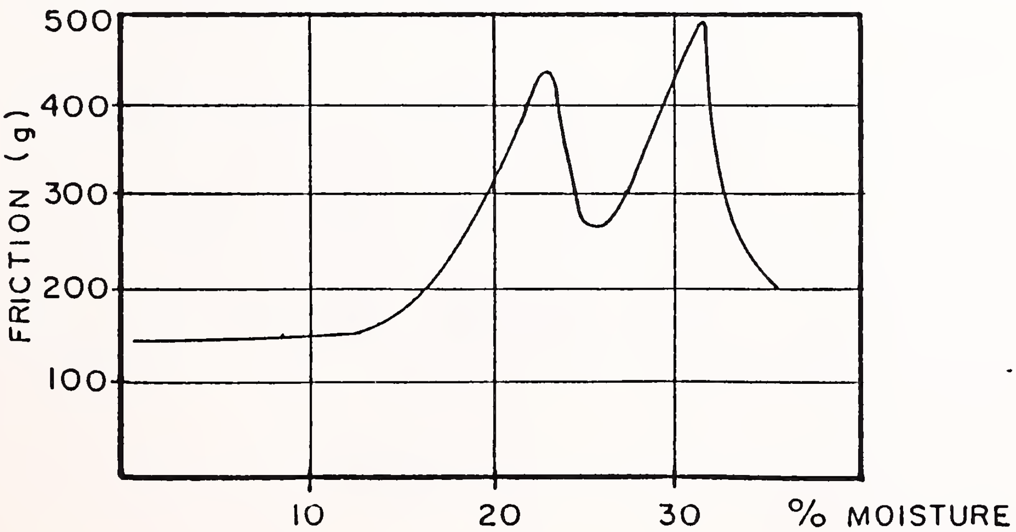


FIGURE 9

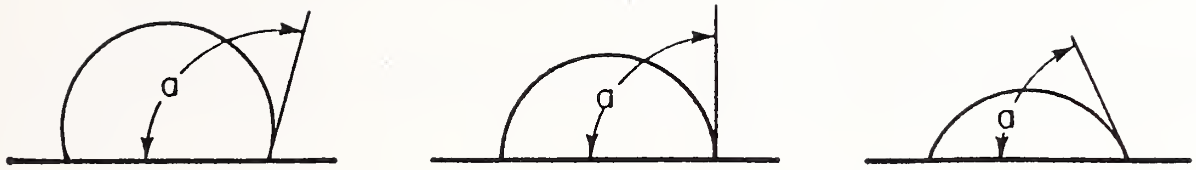
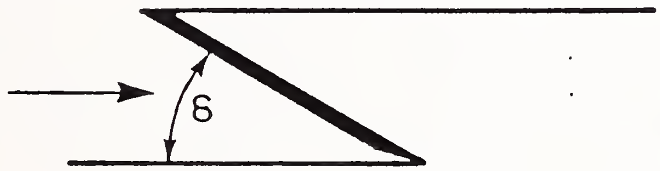


FIGURE 10



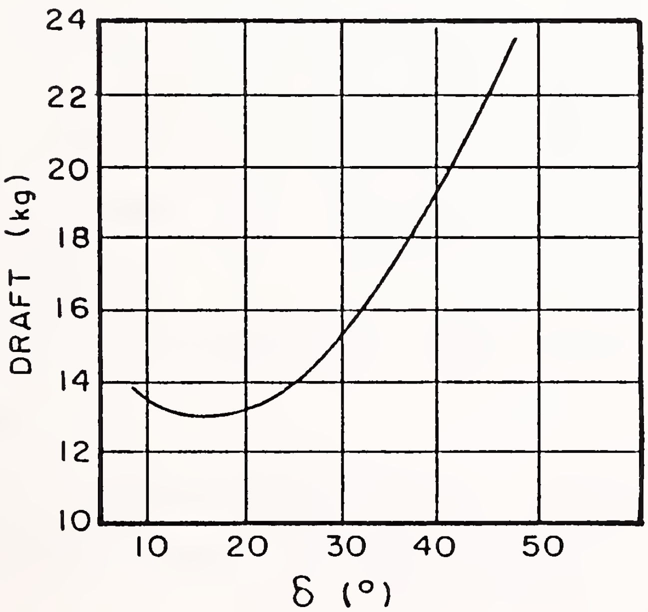


FIGURE 11

Material for the two rear moldboards was Astralloy, an air hardening abrasion resistant alloy that could be bent in the hardened state.

Design Steps for the Moldboard

In order to define the shape of the moldboard, a pattern for the flat or cut shape of the moldboard material was required. A template for the curves at various stations along the moldboard was also required. To obtain the cutting pattern and curve template, four views of the moldboard were constructed.

The front view was constructed to define the cutting width, depth, landside height, maximum height of the developed moldboard and the underside shape of the moldboard.

A side view perpendicular to the edge of the share was constructed to define the curves at the various stations along the moldboard.

A top view was constructed to establish the location of the curves, angle of the share to the landside, location and size of the landside and a base from which to project to the drawing of the cut shape of the moldboards.

The drawing of the cut shape was then done by projecting from the previous drawings.

Curves for the segments making up the standards were also constructed by projecting from the previous drawings.

CHASSIS DESIGN

The chassis for the three-layer plow was designed for maximum flexibility and stability. The main objective was to accommodate the experimental nature of the project.

Flexibility was built into the main members and the hitch. The main frame members were aligned parallel to the furrow. The members were also kept free from other parts to allow for the attachment and adjustment of the various bottoms and related equipment. The bottoms were then clamped to these members to allow for fore and aft, and vertical adjustment (Figure 3).

The hitch was designed with adjustments to accommodate a wide range of tractor operating positions. Vertical adjustments of the hitch were made by raising or lowering the spindle in the hitch spindle bushing and securing with a collar (Figure 1). Side adjustments were made using the vernier adjustment provided on the right side of the hitch. These hitch adjustments allowed the tractor to be run in any position from straddling the furrow to running completely on the land.

The plow had to be stable for meaningful results to be obtained. Stability for this plow was obtained through the design of the plow bottoms, location of the wheels and arrangement of the hitch.

A landside was installed on the rear bottom only (Figure 6). It was designed to take the side force from all the bottoms. A width of cut control was installed on the second bottom. This was a shoe that projected past the edge of the shin. It prevented the second bottom from cutting into the furrow wall.

A land wheel was used to control the depth of plowing. To lower the plow into the working position, this wheel was swung back to the side and just in front of the rear bottom (Figure 4). With the wheel in this position, a small change in the depth of plowing produces a comparatively large change in the fore and aft level of the plow which is continually corrected by the rear furrow wheel. In the transport position the wheel moves forward to increase the fore and aft stability of the plow, and also alignes with the other front wheel to facilitate turning.

The front furrow wheel moves ahead for lowering the right side of the plow. This wheel is used to maintain the side to side level of the plow. It is also used to tilt the plow to reduce the draft on the first and second furrows.

The rear furrow wheel controls the fore and aft level of the plow. Adjustments can be made by loosening the lock nut and turning the handle on top of the vertical caster bushing (Figure 2). The plow is properly adjusted when the front and rear of the frame is the same height when the plow is working (Figure 4).

CONCLUSION

This plow (Figures 5 and 6) was tested and compared with single layer-type plows and was found to pull about 25 percent heavier. This was partly due to a 30 degree rather than a 20 degree approach angle of the share of the second bottom. A portion of the excessive draft can also be attributed to the steepness of the curve.

The plow did, however, meet all the other requirements of scouring, stability, soil mixing and soil placement.

The soil scientists from the University of Alberta and Alberta Agriculture are pleased and enthusiastic with the apparent results of the plow. The problem of draft can be reduced if crop yields confirm the need for this type of plow.

ACKNOWLEDGEMENTS

The author acknowledges the financial support of the federal government in the fabrication of the plow.

The support of W. C. Kirk, G. L. Calver and the Soils Branch of Alberta Agriculture in the design of the plow is gratefully acknowledged.

The support of Kellough Bros., Stettler, in the fabrication of the plow is also gratefully acknowledged.

REFERENCES

1. Kirk, W. C. and John Kienholz. Jan. 21, 1975. Deep tillage; a review of its status in international agriculture, particularly with regard to the management of solonetzic soils. A study prepared as an experimental project for the Engineering Research Service, Agriculture Canada. Contract No. CSW4-0244, File No. 01843-4-0568, p. 7.

2. Ibid., p. 44.

3. Toogood, J. A. and R. R. Cairns. 1973. Solonetzic soils technology and management. Bulletin B-73-1. 1st edition. University of Alberta. Faculty of Agriculture and Agriculture Canada. Research Branch, p. 14, 18.

4. Ibid., p. 18.

5. Kirk, op. cit., p. 42-43.

6. Söhne, W. and R. Möler. 1963. The design of moldboards with particular reference to high speed ploughing. Translation 146. Silsoe, Eng., National Institute of Agricultural Engineering, p. 4.

7. Ibid., p. 5.

8. Loc. cit.

9. Ibid., p. 8.

10. Ibid., p. 6.

11. Loc. cit.

12. Gill, William R. and Glen E. Vanden Berg. 1967. Soil dynamics in tillage and traction. Washington, D.C., U.S. Dept. of Agriculture. Agricultural Research Service. (Agriculture handbook, No. 316), p. 178.

13. Ibid., p. 161-176.

14. Ibid., p. 161-170.

15. Ibid., p. 167-169.

16. Ibid., p. 266-269.

17. Ibid., p. 165-166.

18. Ibid., p. 48-49.

19. Ibid., p. 138.

20. Ibid., p. 246.

PLATES

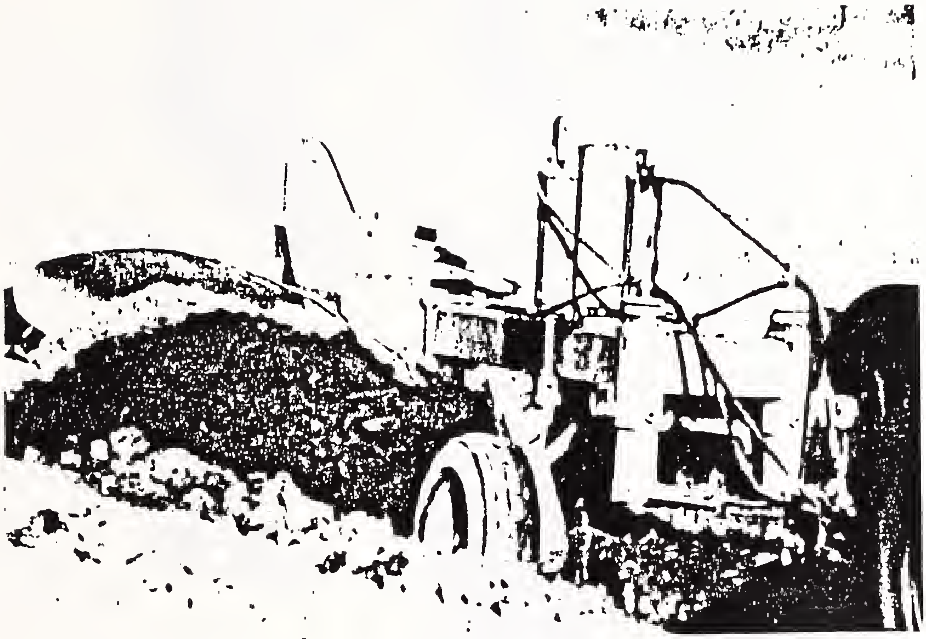


FIGURE 1

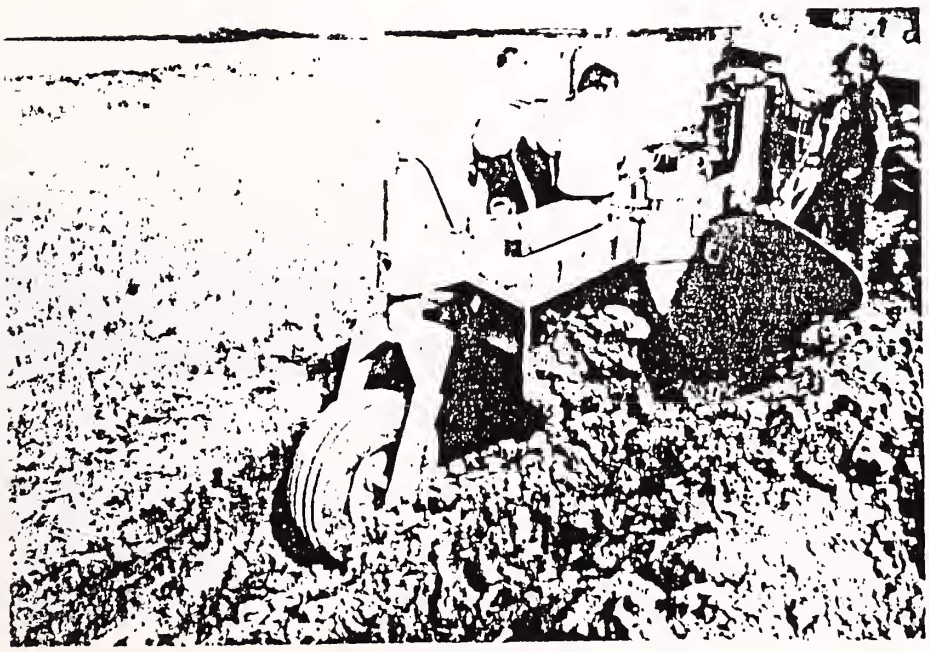


FIGURE 2

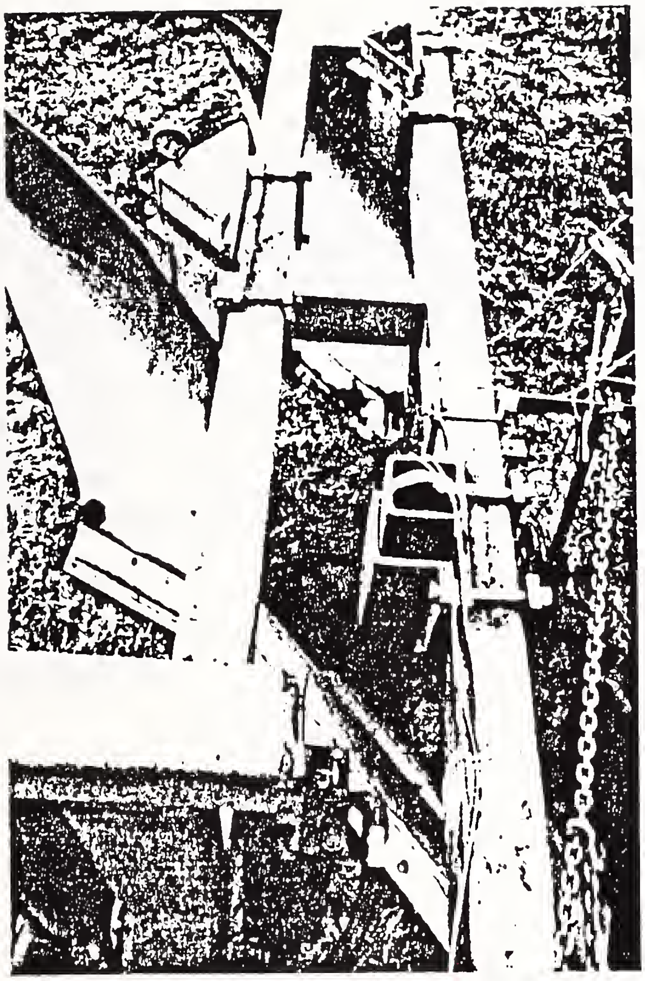


FIGURE 3

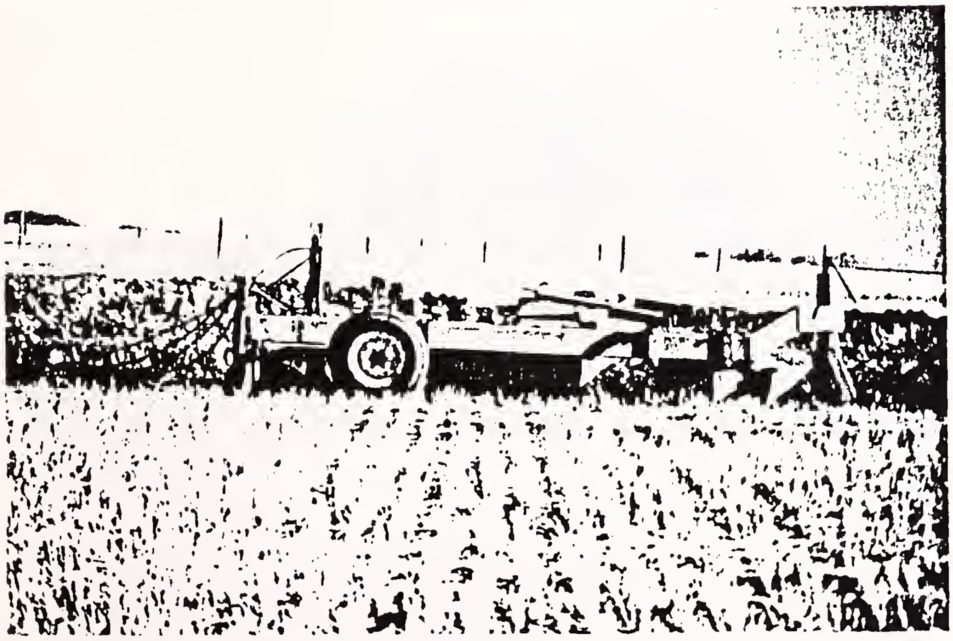


FIGURE 4

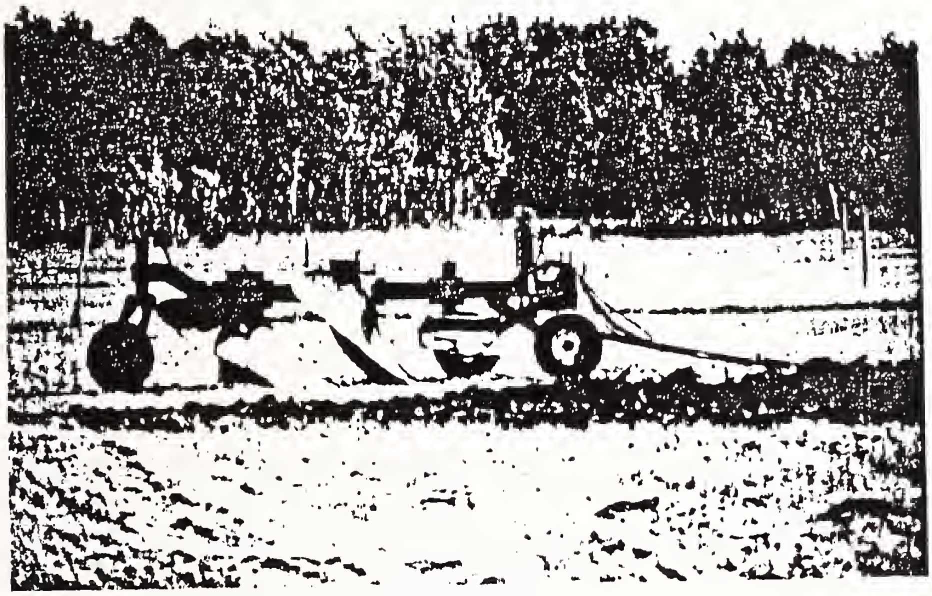


FIGURE 5

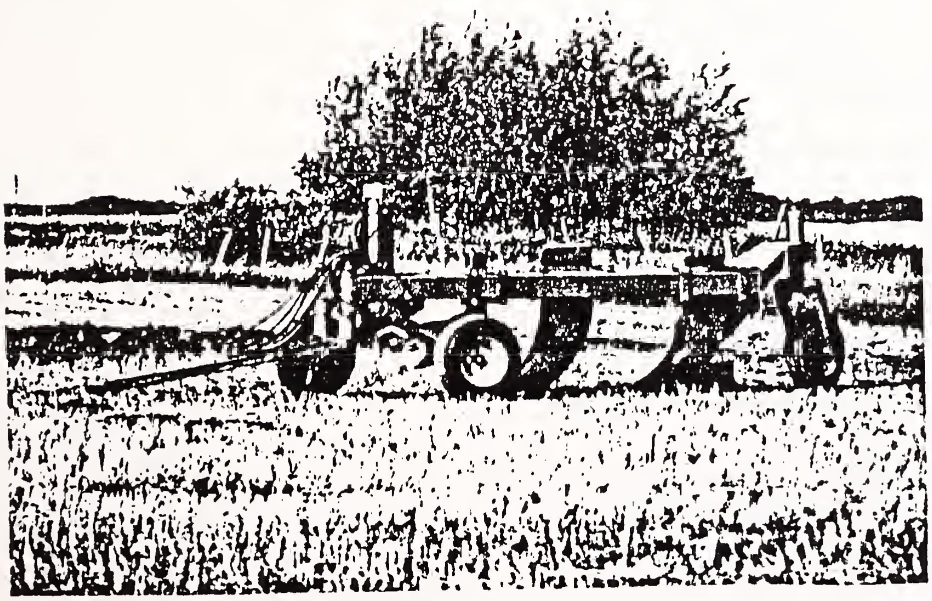


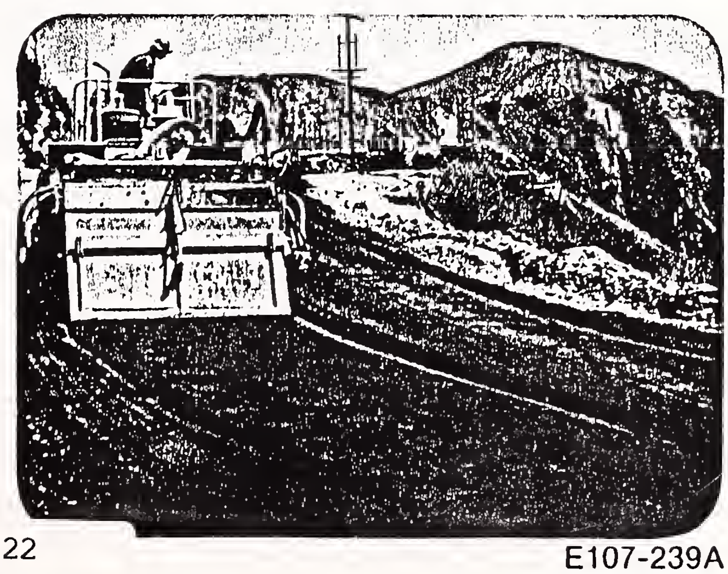
FIGURE 6

MECHANICAL DEEP-INCORPORATION: ROTARY MIXING

Product literature for two manufacturers of rotary deep-mixing devices are included (Roto-Clear, and Bo-Mag). Inclusion of product literature does not constitute product endorsement. Discussions with users of these products for land reclamation purposes indicates that mechanical incorporation to depths of 14 inches can be achieved.

BOMAG®

MPH100
Soil Stabilizer



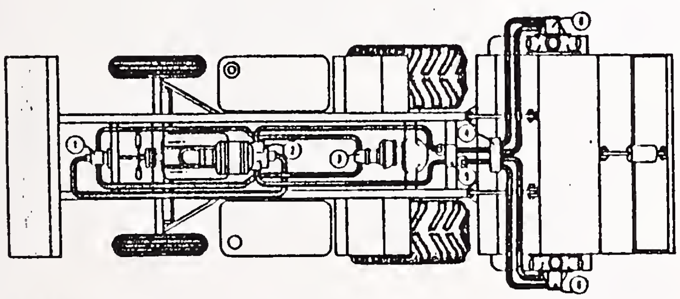
E107-239A

Highway mainline grades and shoulders, secondary roads, haul roads and service roads, airports, building sites, parking lots . . . whatever the application - the BOMAG MPH100 SOIL STABILIZER will prove its ability to outperform any competitive machine at the lowest operating cost.

The MPH100 is a fully hydraulic stabilizer with no mechanical drive components to fail under stress. The BOMAG patented rotor drive system is unique in the industry.

Achieve maximum productivity through "Automatic Power Apportioning". APA regulates the travel speed of the stabilizer according to the power demands on the rotor. This provides faster working speeds without exceeding the available engine power, and protects the hydrostatic system from being overloaded by improper machine operation. This patented system can provide as much as 50% greater productivity than can be achieved by machines without this feature.

The rotor is driven from both ends by radial piston motors and turns opposite to the machine's forward travel. Thus the rotor teeth cut and pulverize simultaneously in an upward direction reducing the size of large clumps until the desired gradation has been achieved. To protect the drive system, the rotor drive hydraulic oil is filtered each cycle, and for further protection, relief valves reduce shock loads should a hidden obstacle be struck by the rotor. Warning devices alert the operator to system malfunction.



POWER APPORTIONING SYSTEM
HYDROSTATIC TRACTION SYSTEM
ROTOR DRIVE SYSTEM

① traction pump ③ traction motor ⑤ relief valve
② rotor drive pump ④ flow divider ⑥ rotor drive motors

BOMAG's premium cutting teeth outlast other teeth by a large margin. When change-out is required, one person can replace the entire set of 70 tap-in/tap-out teeth in just one hour using a hammer as the only tool. The chevron pattern of tooth placement on the rotor evens the shock loads on the teeth and rotor to significantly extend component life.

Premium rotor teeth with 3/16 or 3/8-inch (5 mm or 10 mm) thick carbide lacing are recommended for most applications to provide optimum tooth life and lowest cost per unit of material stabilized.

SPECIFICATIONS

MPH 100	SOIL STABILIZER
DIMENSIONS/WEIGHTS	
Operating Weight	30,300 lb (13 744 kg)
Shipping Weight	29,290 lb (13 286 kg)
Overall Width	120.0 in (3 050 mm)
Overall Height	140.0 in (3 555 mm)
Height (less ROPS)	101.0 in (2 565 mm)
Overall Length	336.0 in (8 535 mm)
Wheelbase	128.5 in (3 265 mm)
Turning Radius-inside	250.0 in (6 350 mm)
Ground Clearance	20.0 in (510 mm)
ROTOR	
Final Drive Type	radial piston motors
Diameter	48.0 in (1 220 mm)
Cutting Width	79.0 in (2 005 mm)
Cutting Depth - standard	14.5 in (370 mm)
- deep mix	19.0 in (485 mm)
Rotor Speed	0 to 135 rpm
Quantity of Teeth	70
DRIVE SYSTEM	
Engine	Detroit Diesel 8V-71N
Rated Power @ Speed	304 bhp (227 kw) @ 2100 rpm
Electrical System	24 volt
Propulsion Drive	hydrostatic
Transmission	2 speed mechanical
Max. Speeds - working	202 fpm (61.6 m/min)
- travel	12.0 mph (19.3 km/hr)
Fuel Tank Capacity	120 gal (455 l)
Hydraulic Oil Capacity	60 gal (227 l)
Tire Size front	11.25 x 24 8 ply
rear	28L x 26 10 ply R1
STEERING	
Type	hydraulic, Orbitrol
BRAKES	
Service	hydrostatic braking with traction drive circuit
Emergency	hydraulic drum type in drive wheels
Parking	manually-applied drum type in wheels

Standard Features

Hydrostatic traction drive with single lever control and neutral start switch • Direct hydraulic rotor drive with Automatic Power Apportioning-APA • Hydraulic power steering • Hydrodynamic service brakes • Instrumentation and controls include: engine tachometer; hour-meter; engine coolant temperature and oil pressure gauges; ammeter; hydraulic oil temperature gauge; speedometer; diesel fuel and hydraulic oil level gauges; hydraulic oil filter change indicators; engine air cleaner restriction indicator; vacuum gauges; horn • Tool box • Hydraulic filter kit • Adjustable operator's seat with arm rests and seat belt • ROPS.

Optional Equipment

Automatic Liquid Proportioning System - ALPS • Asphalt additive system (manual) • Water additive system (manual) • ROPS cab • Engine air pre-cleaner • Lights • Paint (colors other than standard BOMAG yellow) • Deep-mix rotor - mixes to 19 inches (485 mm) • Teeth - economy grade or clay cutter • Desert Cooling Kit • Manual Cross Slope • Automatic Grade Control with averaging ski •

BOMAG
AMCA INTERNATIONAL

BOMAG USA
Springfield, Ohio
Tel. 513-3258733, Telex 4984147

BOMAG CANADA
Mississauga, Ontario
Tel. 416/6256611, Telex 6961250

BOMAG GERMANY
Boppard/Rhein
Tel. 67 42-100-0, Telex 426316

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Wien
Tel. 222-693617-0, Telex 133-535

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Bretigny Sur Orge
Tel. 08495-30, Telex 691370

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LIA

23260

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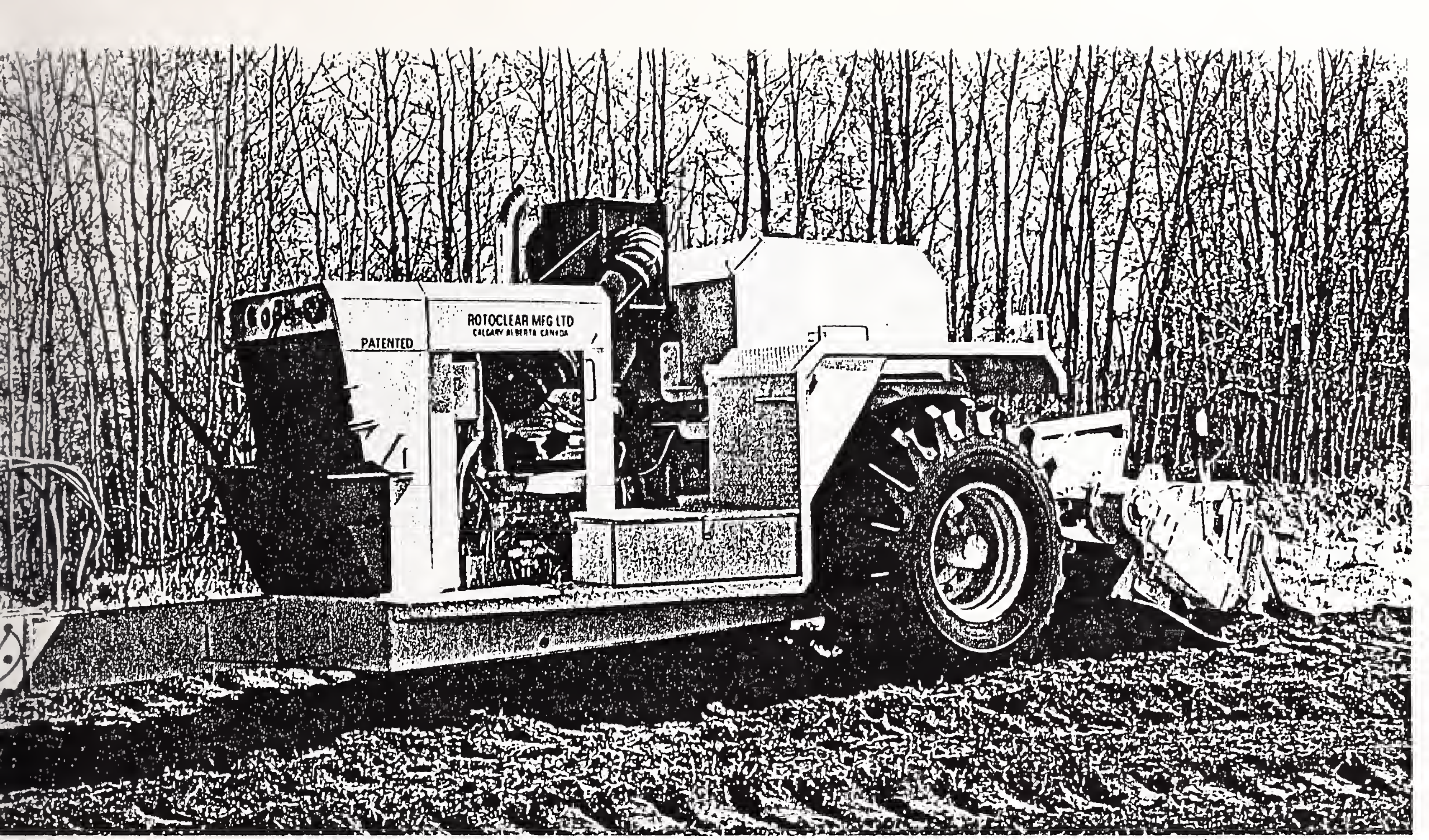
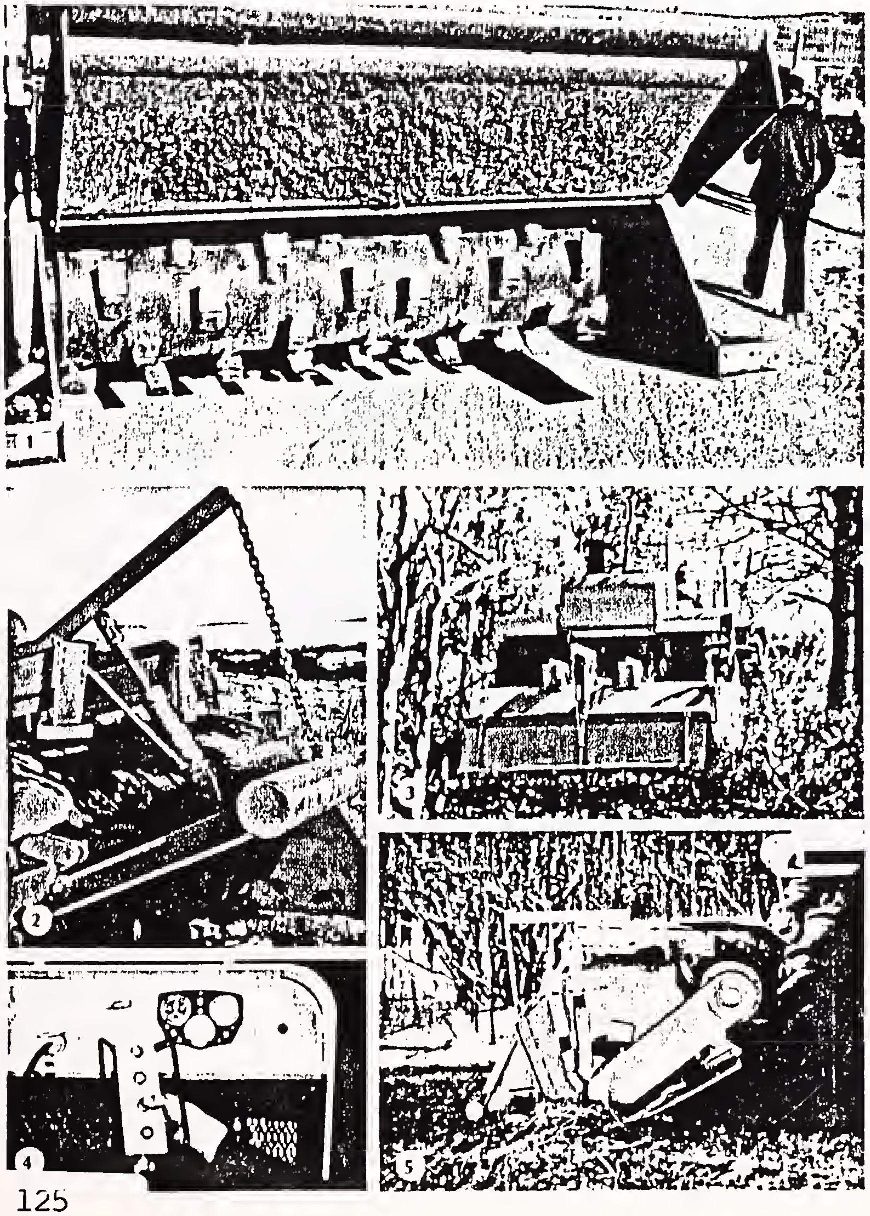
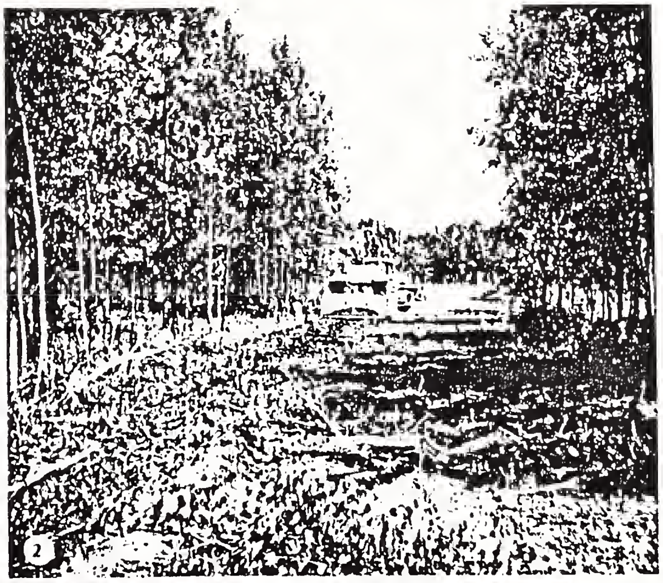
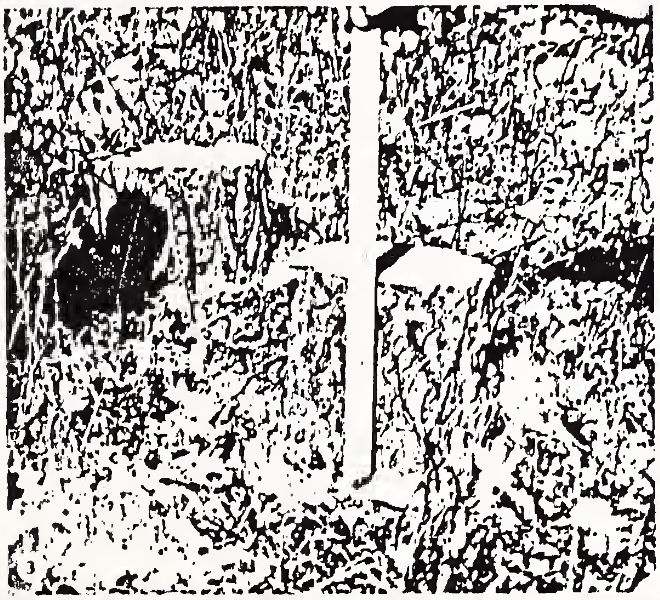


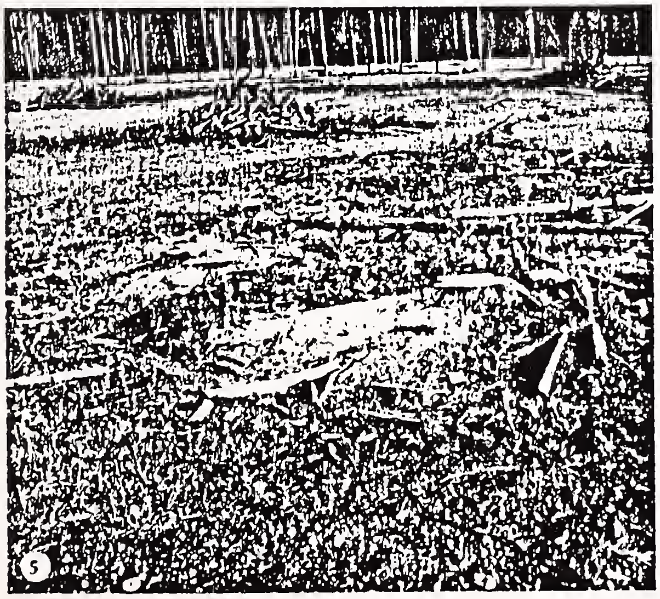
New One Pass Clearing Power for use in Agricultural - Forestry environmental management.



1. Showing Rotor with tailgate raised. Standard rotor 56 teeth.
2. Hood Cover and Tailgate. Tailgate operated hydraulically from lever in front of left fender.
3. Showing Rotoclear Machine going into trees and mulching them.
4. Gauge Panel. Also showing control panel that is taken to the pulling unit where the operator controls the operation of the Rotoclear machine.
5. Showing the rear portion of the Rotoclear machine - chain case, depth gauge, tailgate lever skid.







MADGE

ROTOCLEAR

1. 25 foot Grove of poplar trees before Rototilling
2. Same Grove after one pass with Rotoclear machine.
3. Picture showing stump before Rototilling. The recommended height is ground level to 4" above for the best job.
4. Showing stump mulched and also the depth of cut.
5. Large Stump & Logs before Rototilling
6. Customer looking for Stumps after one pass with Rotoclear machine.

SPECIFICATIONS

PHYSICAL DIMENSIONS

Length Overall:	22'6"	6.85 metres
Width:	9'8"	3.00 metres
Shipping Width:	8'0"	2.45 metres
Height:	9'0"	2.75 metres
Shipping Weight Without Fuel:	22,000 lbs.	9979.60 Kgms

POWER UNIT

Engine:	8V-92T GM Diesel 425 HP @ 2350 RPM
Electrical System:	24 volt, Alternator
Air Cleaner:	Donaldson Dry Type, Heavy Duty

COOLING SYSTEM

Capacity:	23 gallons, 105 litres 2 Torque Converter Coolers

DRIVE SYSTEM

Torque Converter:	Allison 574
Rear End:	Single Reduction Rockwell R140, Ratio 5.29:1 Full-Float 5 Ball Suspension (Allows hood and rotor to float independently of main frame.)
Top Axle:	11 Tooth High Carbon Steel, Double Sprocket
Stub Axle:	14 Tooth High Carbon Steel, Double Sprocket
Chain:	140 Double Top Quality

ROTOR (STANDARD)

Width:	7'6"	2.30 metres
Diameter Including Teeth:	31"	79 centimetres
Teeth:	56 Self Sharpening Knock-Out Replacement	
Pockets:	Taper Wedge,	
Drum:	High Tensile Steel	
Depth of Cut:	3" to 9" 7.6 to 22.8 centimetres	
Speed:	360 RPM	

STANDARD EQUIPMENT

Frame 12", 30 centimetres
Underframe plating ½", 1.27 Centimetres
Heavy duty engine and rotor hoods
Extra heavy duty radiator and engine guards
Electrically controlled, hydraulic throttle and rotor-lift
Hydraulic Tail gate lift
Electric starter
Full view gauges
Tachometer and hour meter
Adjustable tow bar
Tires — 23.1 x 26, 10 ply tube type Skidder Steel braid
60 x 65 centimetres
200 Imp. gal. fuel tank, 908 Litres

OPTIONS

8V-71 GM Diesel, 318 HP @ 2100 RPM
8V-92 GM Diesel, 365 HP @ 2350 RPM
Air Filter pre-cleaner, except 8V-92T
Special rotors on request

MADGE ROTOCLEAR

The Madge Rotoclear is Canadian in concept, design and manufacture. It is manufactured by and marketed through Roto International Group Inc., in Calgary, Alberta, and patented in Canada, the United States and the United Kingdom, with world patents pending.

It can clear and mulch in surface growth under rigorous conditions of climate and terrain.

The new Rotoclear is the culmination of many years of tried use, testing and modification. Its performance leads us to believe that it is unique in a global marketing context.

The model currently available is designed to be pulled by any four wheel drive or track-type tractor.

Past models, upon which this extremely strong and powerful new generation is based, have up to 10,000 hours on them . . . a good indication of the sound engineering and construction.

Operation

Operation is very simple, requiring minimal operating training. The tailgate covering the rotor lifts hydraulically, using a lever at the side of the machine. The rotor depth can be manually pre-set from 3" to 9". Everything else is controlled from the cab of the pulling vehicle through a plug-in connection on the front of the Rotoclear. A hand control with push buttons raises, lowers, accelerates and decelerates the rotor.

The Rotoclear's unique advantage is that for less than current cost, it provides a viable alternative to the slashing, burning or stacking of surface growth.

The Rotoclear can be pulled by a four-wheel drive tractor, track-type tractor or all terrain vehicle. The pulling vehicle should be equipped with a blade or roll bar, to push down the timber or underbrush. Standing trees up to 5" diameter can, in this way, be mulched in one pass by the Rotoclear.

Use of the Rotoclear takes away much of the confrontation between the farmer and environmental agencies. There is little to object to when unuseable timber and brush are fragmented and mulched into the ground. The farmland thus created, is left clear for eventual planting with the added benefit of containing fibre in the soil to promote new growth and prevent erosion.

Agriculture

The early models of this machine were designed for agriculture. Obviously the Rotoclear has no problem in breaking up pasture land that has become so packed and hard as to hinder the growth rate and nourishment of the grass. It is incredibly fast and efficient in cleaning new agricultural land, and offers the ideal method of clearing and mulching crop residues to leave a well fertilized, cultivated seed bed for the next season's crop.

Forestry

The Madge Rotoclear is certified by the U.S. Forest Department. Earlier models have been utilized in the clearance of scrub oak, prior to pine planting. The machine achieved a 98% kill of the scrub oak.

The machine will chew, mulch and bury stumps, roots and underbrush under the soil to a depth of 8" to 9" or less, as required, leaving the top soil ready for planting. Quite often prior to seeding, the soil is packed or light raked, as the rotor fluffs it up to approximately 12" to 14". An important feature is that the Rotoclear will fragment and mulch stumps measuring up to the width of the rotor providing they are cut no higher than 5" above the ground.

Summation

The Madge Rotoclear is reliable, powerful, and versatile. It can not only give a better result, but at a lower cost.

For any further information, get in touch with either:

R.A. Madge, President	or	W.E. Dick, Sales Manager.
Res. 403 - 242-1397		Res. 403-242-3703

PRINTED IN CANADA

LIME SLURRY PRESSURE INJECTION

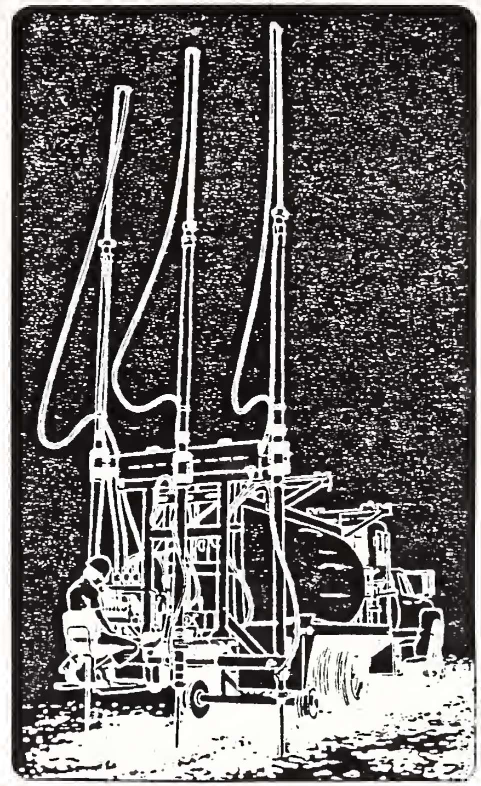
Pressure injection of lime slurry grouting materials is used for improving soil srength of expansive soils. Use of this technique for neutralization of acid-contaminatd soils is relatively new. Details on pressure injection for improving soil strength are found in :

Boynton, R.S. and J.R. Blacklock. no date. Lime Slurry Pressure Injection. National Lime Association Bulletin 331. 43 p.

LIME
"THE" VERSATILE CHEMICAL

BULLETIN 331

LIME SLURRY PRESSURE INJECTION BULLETIN



PUBLISHED BY NATIONAL LIME ASSOCIATION

FOREWORD

The National Lime Association has followed with interest the growth and development of injection stabilization over the past 20 years. Initially there was skepticism about the use of this technique, but as better equipment and procedures have been developed and more experience gained, there has been a growing acceptance of injection stabilization in the engineering community. While the Association does not claim to understand fully all of the mechanisms that make this system work, the fact that it has been proven to work in many instances when properly applied is now considered to be an undeniable fact.

This new bulletin is the joint effort of Robert S. Boynton, past Executive Director, NLA, Kenneth A. Gutschick, Technical Director, NLA, Paul Wright, President, Woodbine Corporation, Ft. Worth, Texas, and J. R. Blacklock, Professor of Engineering Technology, University of Arkansas at Little Rock, Arkansas. These men contributed their time and their ideas to make this publication an accurate, informative and useful technical guideline for the understanding and use of this system. All illustrations and photographs were provided by Woodbine Corporation.

LIME SLURRY PRESSURE INJECTION BULLETIN

BULLETIN 331

By
Robert S. Boynton, Retired Executive Director,
National Lime Association
and
Dr. J. R. Blacklock, Professor of Engineering Technology,
University of Arkansas at Little Rock, Arkansas

NATIONAL LIME ASSOCIATION
3601 No. Fairfax Drive
Arlington, VA 22201

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PREFACE

Lime stabilization has a history which reaches at least 5000 years into the past, and in such major areas as pavement and building practice; even in ages and places where engineering skill has been used, e.g., in the use of lime-stabilized floors of Saxon England (23).

In the next one hundred years there will be an increasing importance for lime stabilization due to its growing economic advantage, with principal attention directed to the improvement of present techniques. Also stabilization will be forced to the forefront with the need for development of less desirable land due to depletion of better construction sites. The major consumer is expected to remain the road and rail construction industries, but housing may have a significant and expanding role (23), and maintenance, repair and renovation of existing sites will claim a larger share of the soil stabilization dollar.

In 1976 the ASCE sponsored a study to determine the ten most desirable soil stabilization developments. A select group of stabilization authorities was chosen world-wide and each was invited to submit opinions as to the most desirable stabilization developments over the next 50 years and 100 years, then each development was ranked according to the consensus weightings of desirability and feasibility.

The ten most desirable developments in soil stabilization were determined to be:

1. Insitu soil parameter evaluation.
2. Utilization of solid wastes as construction materials.
3. Traveling machines to form roadways by inplace processing of native soils.
4. Insitu treatment to control expansive soils.
5. Borehole techniques for evaluation of grouting.
6. Slide stabilization with chemical grouts.
7. Horizontal reinforcement nets for embankments on weak soils.
8. Insitu installation of soil reinforcing members.
9. Compaction equipment with variable characteristics controlled by feedback from the soil.
10. Densification of deposits in the ocean floor.

It is of special interest that several of the top 10 are covered directly or indirectly in the technology discussed in this bulletin, namely item 2) which covers fly ash utilization, item 4) which covers LSPI and L/FA injection, item 6) which covers slope stabilization with LSPI and L/FA, and items 7) and 8) which indirectly refer to seam reinforcement with lime and lime/fly ash slurry.

This bulletin is issued to address directly the implementation of these desirable technologies with the Lime Slurry Pressure Injection (LSPI) and Lime/Fly Ash (L/FA) Injection methods of soil stabilization. Steady growth in these two areas of insitu stabilization over the past 20 years has led to the development of innovative processes for stabilization of expansive soils and other unstable materials. Due to the many variable soil and

ground water conditions as well as stabilization materials, it has become evident that the insitu stabilization process requires a higher level of technological developments than at first was generally considered necessary. Most technological developments have been supported by Woodbine Corporation of Fort Worth, Texas, who has been instrumental in advancing a more technical approach to this process since 1968. In addition, injection stabilization has been the subject of research at the University of Texas at Arlington and the University of Arkansas at Little Rock. In 1974 major research funding was provided by the Federal Railroad Administration, and the "Handbook for Railroad Track Stabilization Using Lime Slurry Pressure Injection" was issued in 1977 (5).

As the use of lime and lime/fly ash injection continues to grow, it is anticipated that new equipment, procedures, and tests will continue to be developed. Injection stabilization has been a growing, developing technology over the past 20 years, and there is ever reason to believe that it will continue to grow. Pressure injection stabilization has proven itself as a viable alternative for many challenging applications, and engineers can now design stabilized structural foundations with a higher level of confidence with LSPI and L/FA injection.

INTRODUCTION

Of the major categories of construction problems today, possibly none have caused more havoc and costly damage than those caused by expansive clay soils used in foundation systems. It is currently estimated that damage caused to various structures by expansive clay soils exceeds $5 billion per year (24).

This bulletin describes a soil stabilization process called Lime Slurry Pressure Injection (LSPI) which has proven to be effective for stabilizing expansive foundation soils used in construction. The LSPI process involves injecting hydrated lime slurry under pressure to depths of 3 to 10 ft, and occasionally to 40 ft. The slurry, following the paths of least resistance, is forced laterally and vertically into cracks, root holes, etc., forming a network of alternate sheet-like lime seams and soil layers (Fig. 1). After placement, the lime reacts with the clay at the interface of the seam to increase the soil strength and reduce moisture movement, thereby minimizing soil movement and its damaging effects.

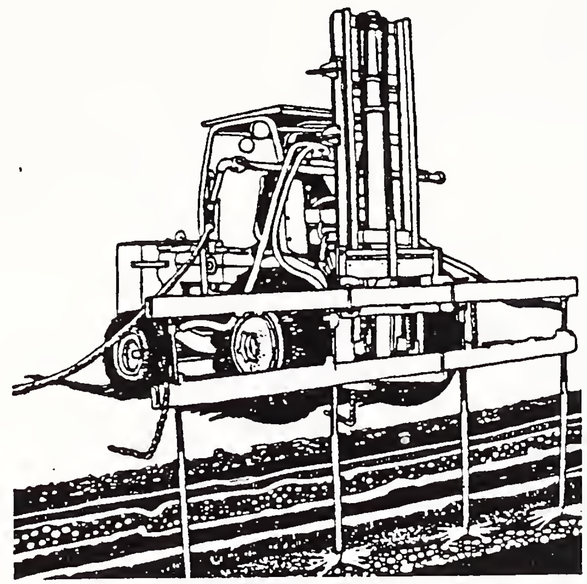


Fig. 1 *Injection machine forming lime seams*

BACKGROUND

Expansive clay soils occur in many parts of the United States, and these "swelling" clays generally cause severe problems when wet-dry cyclical weather conditions exist. In times of drought the clay soils shrink and develop tension cracks due to lack of moisture, and in times of high rainfall they expand and swell. In many areas, the soils will experience numerous wet-dry cylces every year. Each cycle drives the tension cracks deeper into the soil mass, causing damage to become progressively worse with time. The resulting volume change, which can measure up to 30% in linear swell or shrinkage, can be extremely disruptive to structures that are built on this type of unstable soil, causing unsightly cracks and expensive structural failures.

Of the various types of clay found in the United States, montmorillonite is the most destructive; however, fortunately it is the most responsive to lime stabilization. The illite and kaolinite clays, which are less destructive, are also lime reactive, but generally to a lesser degree. In addition to expansive clays, silty-clay soils as well as dispersive clays and collapsible clays have also caused significant construction problems. Typically, silty-clays have low strength and are very unstable under high moisture conditions. Soils high in decomposed organic matter are similarly unstable. Many organic clay type soils are also lime reactive and therefore subject to improvement by LSPI.

The following are typical examples of problems caused by expansive clay soils:

Cracking Masonry Walls—In many instances these have severely cracked and in some instances created a dangerous condition. Generally, the cracks follow the mortar joints in a step-like fashion and often break through the masonry units. These unsightly cracks often cannot be satisfactorily repaired and they result in loss of property value (Fig. 2).

Cracking Floor Slabs—In slab-on-grade construction, floor slabs often crack and heave so badly that doors and windows cannot be opened, interior walls crack, and the floor surface is greatly distorted. Floors built on pier and beam spread footing foundations similarly have been damaged by swelling clays (10).

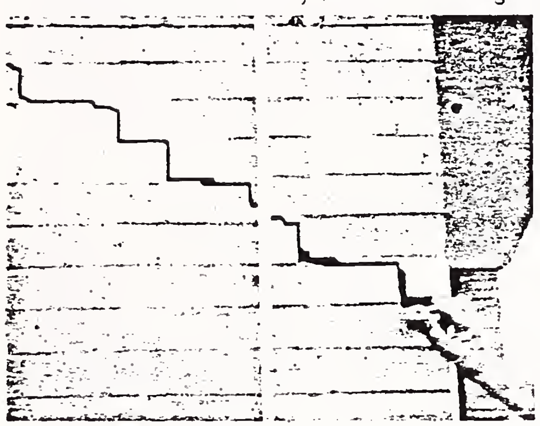


Fig. 2 Masonry cracks caused by expansive clay soil

Slope Stability Failures—Cracks forming as a result of wet-dry cycles can result in loss of embankment strength and stability. Slope failures occur on highways, levees, and railroads, resulting in excessive maintenance costs, loss of property and public safety hazards (Fig. 3.)

Pavement & Slab Failures—Highway, runway and other pavement slabs often crack so badly that extensive reconstruction is necessary (28, 29). Typical problems such as surface cracks, potholes and uneven bumpy surfaces are usually caused by moisture penetrating the underlying expansive clay soils and causing disruptive swelling.

Lime slurry pressure injection (LSPI) was developed in the early 1960's to correct these deep clay soil problems, and since then it has been widely used throughout many parts of the U.S. The process is cost effective for pretreatment of new foundation construction (Fig. 4a), as well as post treatment for repair and rehabilitation of existing structures (Fig. 4b) (47). For remedial applications, LSPI has the advantage of being non-destructive to existing structures, and it can also be applied with a minimum of disruption to continuing service, such as railroads and highways.

When foundation soils are expansive clays, the soils engineer will usually recommend a structural system that completely isolates the floor from underlying clays. While such is probably the most reliable, it is also expensive. Its use, accordingly, is limited to a small portion of total construction projects. Economic considerations require the engineer to consider alternate methods of coping with expansive clay soils, to allow use of the more economical slab-on-grade floor systems.

The choice of alternates will often be

Fig. 3 Slope failure on highway embankment

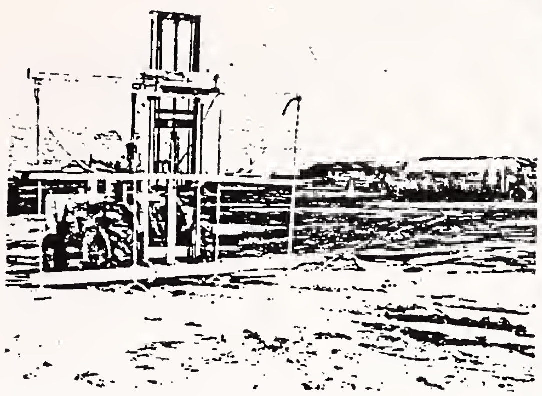


Fig. 4A Lime injection pre-treatment of building foundation, slurry mixing tank is on right

Fig. 4B Post treatment of cracked masonry

governed by local considerations, such as availability of certain materials and contractors, as well as the individual preference and experience of the testing laboratory or design engineer. Cost prohibits some alternatives, e.g., conventional lime stabilization of a 4-ft. mat may cost more than a structural floor. Other alternatives consume too much time, e.g., ponding a site to pre-swell clays. And some are just not as effective, e.g., the post hole method of pre-drilling holes and filling with lime slurry.

One commonly used technique has been to over-excavate the clay and backfill with an inert borrow material. The depth usually ranges from 2–4 ft., with 3 ft being the most common. Considerably more expensive than LSPI, this method is also less satisfactory because it creates a bathtub of pervious material under the building slab, allowing easy movement of moisture to underlying clays. Proper placement of the fill requires close inspection, and quality control of the material can be difficult. Also, with the over-excavate-and-backfill method, the job is subject to long delays if rain occurs after excavation and prior to placing borrow material. LSPI provides further economies by allowing use of on-site materials for fill, to obtain subgrade prior to injection. In many areas, particularly urban, depletion of suitable quality borrow material and the associated higher cost are ruling this out as a viable alternative.

Figure 5 compares the cost of LSPI to the over-excavate-and-backfill method in the Dallas/Fort Worth area. The cost of the latter is based on removing 3 ft. of material from the site and replacing with 3 ft. of select (low PI) material, placing it in compacted 6 to 8-in. lifts. Price for LSPI is based on a double injection to 7-ft. depth. Using the prices for a 45,000 sq. ft. job, the over-excavate-and-backfill

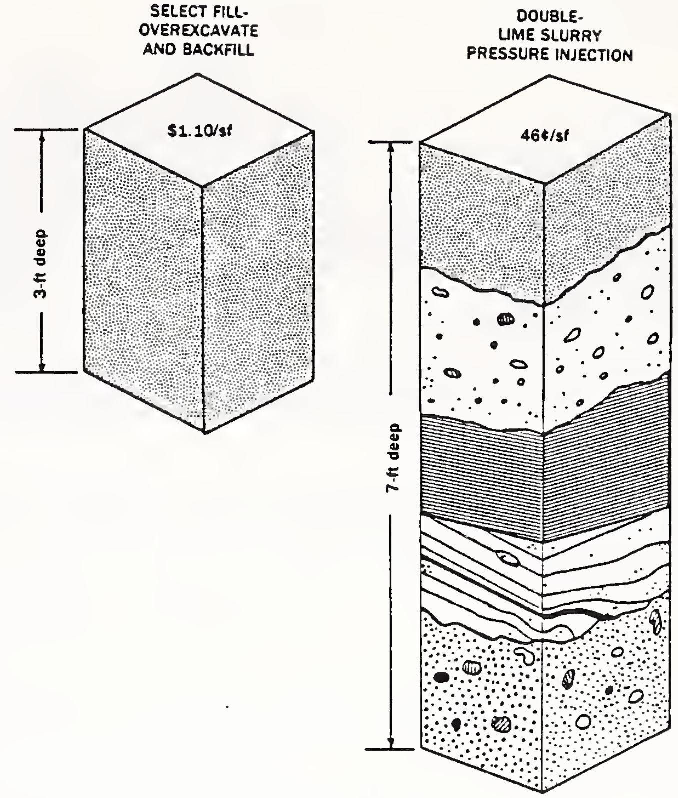


Fig. 5 Comparative cost for LSPI vs. overexcavate and backfill

method would cost about $49,500 compared to $20,700 for a double lime injection.

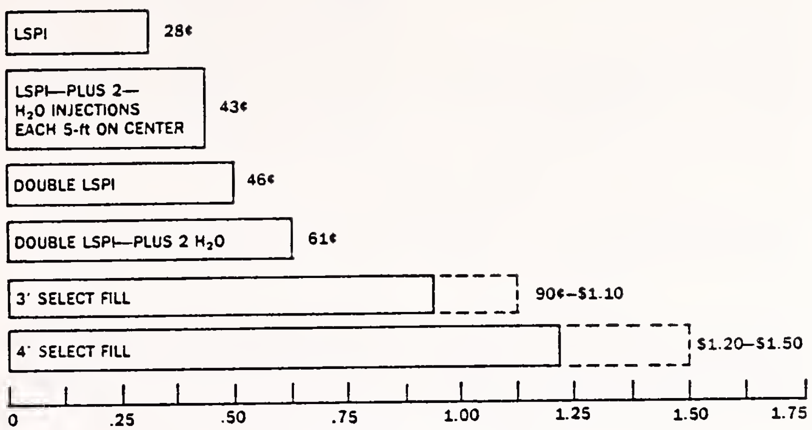
Table 1 shows a price comparison of using 3 to 4 ft. of select fill vs. LSPI based on current 1985 average prices in the Dallas/Fort Worth Metroplex.

Over the past years LSPI has undergone many innovations in equipment, materials, additives, and design that have improved the consistency of its performance, greatly expanded its application, and reduced costs (48, 49, 50).

Additional applications for this stabilization technique continue to emerge as improved equipment is developed

TABLE I

PRICE COMPARISON OF STABILIZATION METHODS FOR EXPANSIVE CLAY SOIL.



PRICES
1. Prices are shown based on July 1985 costs in Dallas/Ft Worth Metroplex.
2. Lime and lime/fly ash injection prices shown are average current prices and will vary with size of job and other pertinent circumstances.
3. Prices for overexcavating and back-filling with select fill were obtained with several D/FW contractors and based on average haul distances in the metroplex.
4. Project size 80,000 sq. ft., all injections 7 ft. deep, 5 ft. O.C.E.W.
5. Injections for double LSPI spaced diagonally between first injections.

along with the use of alternative materials and improved engineering construction and design technology (Fig. 6).

In recent years the additive, fly ash, has enjoyed increased use in lime injection stabilization. The process of pressure injection of lime slurry mixed with fly ash is termed lime/fly ash (L/FA) injection* (8, 25, 31)

*A patent for injecting lime/fly ash slurry into the ground is claimed by Woodbine Corp., Ft. Worth, Texas.

Generally, lime/fly ash slurry results in a more pronounced increase in the bearing strength of silty and sandy soils than lime slurry alone. With many well drained soils deficient in reactive minerals, lime alone is usually not effective. With a proper mixture of lime and fly ash, injection stabilization can be successfully extended to those soil types.

An advantage of L/FA injection is that fly ash, being a by-product, is relatively

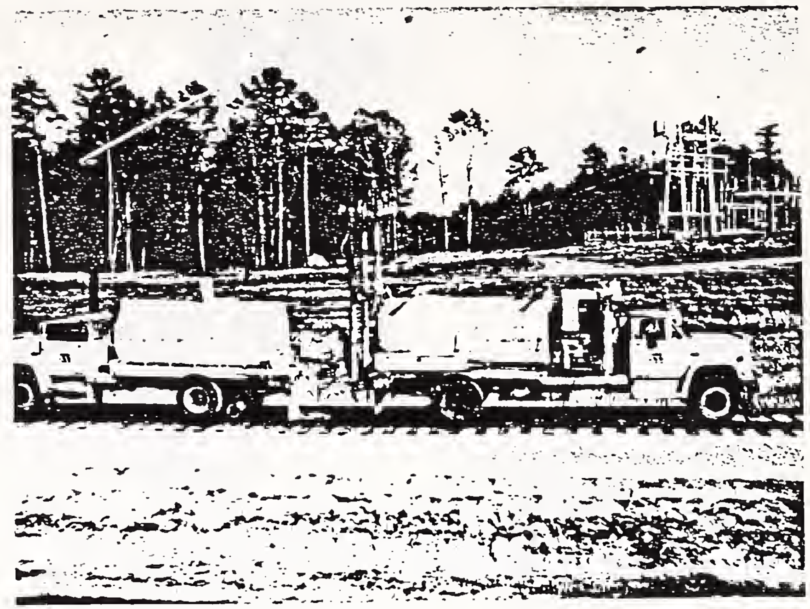


Fig. 6 *On-off track injection rig and slurry haul truck*

inexpensive, about 20–40 percent of the cost of lime per ton. Therefore, with some problem soils it offers an economical solution by providing a low cost slurry. This economy is important for projects with large void ratios such as slides, landfills, and railroad beds with deep ballast pockets (7, 8).

Another use of lime-fly ash slurry is for mud-jacking of concrete pavements and foundations. The viscous, heavy grouts commonly used for mud-jacking usually contain portland cement and sand, but by using lime/fly ash slurry instead, repairs can be accomplished at greater economy. Lime/fly ash slurry mixtures have been pumped at a solids to water mix of 10 lbs. lime/fly ash per gallon of water.

Pressure injection increases the strength of embankments by adding tensile reinforcing strength, mending existing cracks, and causing peak strength of the embankment fill and the peak strength of the foundation subsoil to be mobilized simultaneously, thus reducing progressive failure effects. Crack mending is critical to renovation, since embankment strength may not contribute to the stability of the slope if the embankment is cracked. Cracks may develop in embankments because of excessive tensile stresses in the fill due to differential

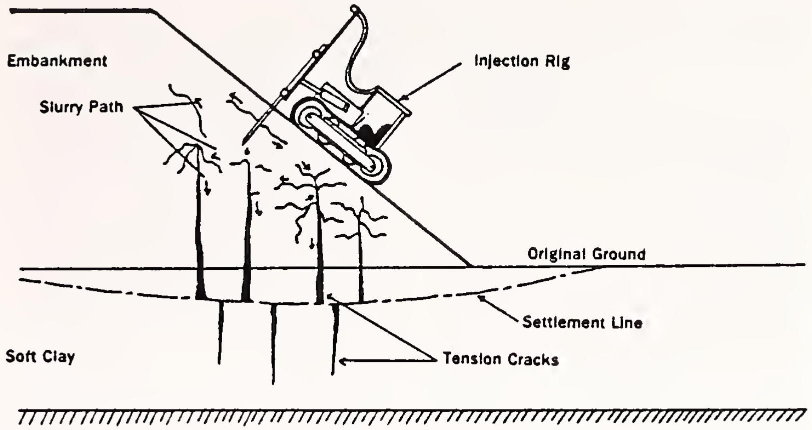


Fig. 7 *Diagram of slope with cracks being stabilized*

settlements or because of shrinkage due to drying. Many tension cracks frequently begin at the bottom of the fill and may not be detected until the embankment is already failing. The pressure injection method has been developed to treat cracks and planes of weakness in-situ, even those hidden from view starting from the bottom (see Fig. 7). Cut and replace does not mend existing tension cracks in the undisturbed mass, and the cracks will continue to propagate into the new materials.

DESCRIPTION OF THE PRESSURE INJECTION PROCESS

The lime slurry pressure injection (LSPI) process consists of pumping into the subgrade a slurry of hydrated lime and water containing from 22–36% lime solids. Injections are made vertically into the soil with holes typically spaced on a 5-ft. grid pattern. Initial injections are often followed by secondary or even tertiary injections, spaced diagonally between the previous injections. Depth of injection will vary based on specific job-site conditions, e.g., typical depth under pavements, 3 to 5 ft., under building foundations, 7 to 10 ft., and 10 to 40 ft. for railroads, landfills, embankments and other deep problem areas. Typical mobile injection units used for building foundation stabilization and other shallow work up to 10 ft. deep are shown in Figures 8 and 9. A standard injection rig is equipped with four injection pipes that can be hydraulically pushed into the soil. The pointed tip of each injection pipe has a perforated hole pattern which disperses the slurry in a 360° pattern throughout the depth of injection (Fig. 10).

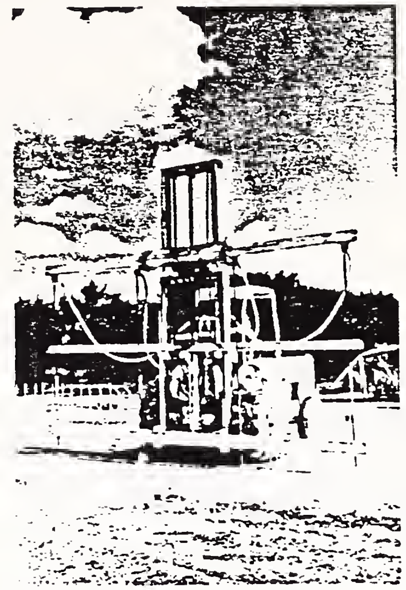


Fig. 8 *Typical rubber tired injection rig*

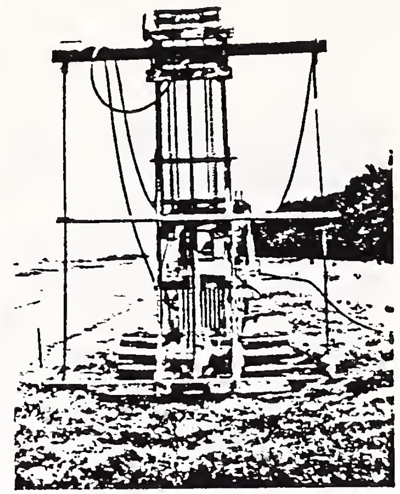


Fig. 9 *Track-mounted injection rig*

Fig. 10 *Perforated steel injection tips*

Slurry pressure and flow are obtained from a suitable pump, which is mounted on the slurry mixing tank (Fig. 4a) which is equipped with a mechanical agitator and is capable of bulk mixing a 20–25 ton truckload of hydrated lime with 16,000 gallons of water. The resultant lime slurry is pumped at pressures of 50 to 200 psi through a high pressure hose to the injection rig. Slurry is injected at frequent depth intervals to refusal or in a slow continuous push until a specified quantity is injected. The slurry, following the paths of least resistance, is forced laterally and vertically into voids, cracks, and fissures, such as bedding planes, dessication fissures, tension cracks, root holes, and available voids to form a network of sheet-like lime seams throughout the soil mass. Often it is necessary to make secondary or tertiary injections in order to obtain a more extensive distribution of lime slurry seams throughout the soil. These subsequent injections are spaced diagonally between previous injection holes and are pumped to slurry refusal or until a predetermined quantity is injected. The resulting lime seams become moisture barriers that impede moisture movement and add tensile reinforcement and compressive strength throughout the stabilized soil-mass. The slurry that escapes to the surface during injection provides a plus value since this surface lime is mixed into the top 4 to 6-in. of soil and lightly compacted to provide a working platform.

The amount of lime required for LSPI treatment can vary considerably, depending on soil properties, injection depth, permeability of the soil mass and degree of stability required. A typical value of slurry required is in the range of 0.6 lb. to .85 lb. per cu. ft. for a single injection and about 1.00 lb. to 1.50 lb. for a double injection.

The lime/fly ash (L/FA) injection process utilizes most of the equipment and procedures of LSPI. The lime slurry mixing tank is first charged with a thin lime and water slurry and then fly ash is blown into the tank while the mixture is continuously agitated (Fig. 11). Because the lime and fly ash form a pozzolanic mixture, it must then be pumped quickly into the ground to avoid settling in the tank or loss of the initial set. Often additives such as accelerators or retarders are mixed with L/FA to enhance its use (40, 44). Slurry mixtures commonly applied are typically one part lime to 2 to 4 parts fly ash by weight, depending on fly ash quality, soil properties, and project conditions.

In many remedial pressure injection applications large pocket-like voids must be filled to restore adequate bearing capacity and stability. L/FA injection is often a feasible void filling method in conjunction with stabilizing the soil. Should the injected lime/fly ash slurry subsequently crack due to deflection from heavy loading, it possesses the inherent ability to reknit the cracks due to a phenomenon called autogeneous healing that also occurs in lime-based mortars (2). Similar to lime/clay mixtures, lime/fly ash slurries harden as a function of time and temperature, but generally much more rapidly than lime/clay soils.

In some projects it is desirable to utilize a combination of both lime and lime/fly ash pressure injection in stages. A 24–48 hour curing period usually is allowed between successive injections. Lime or lime/fly ash pressure injection should

Fig. 11 *Bulk transfer of lime to a slurry mixing tank*

never be applied in freezing weather, and should not be done at 40°F and falling temperature. When temperatures are marginal, the elevated temperature of slurry made by slaking quicklime is an advantage (Fig. 12).

Both lime and lime/fly ash slurry mixtures are equally viable with the pressure injection method and the choice of which material to use should be an engineering decision based on individual job site conditions and tests. When multiple injections are necessary to achieve more concentrated treatment, joint use of lime and lime/fly ash pressure injection in stages, with a curing time between application, is the indicated method to employ in many situations.

INJECTION MATERIALS

Lime—Only commercial grade, high purity hydrated lime meeting ASTM or highway department specifications is recommended. Although most pressure injection work has been performed with high calcium hydrated lime ($Ca(OH)_2$), dolomitic (high magnesium) hydrated lime ($Ca(OH)_2 \cdot MgO$) can also be used,

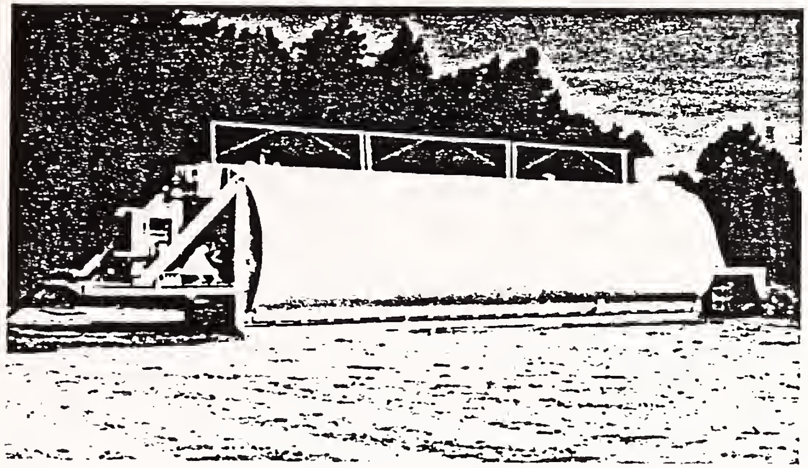


Fig. 12 *High capacity portable batch slaker provides heated lime slurry*

as in conventional lime stabilization. Laboratory lime/soil evaluation tests are necessary in both instances.

The lime slurry can be prepared at the jobsite in a slurry tank by mixing a measured amount of water with the hydrated lime or more recently by slaking quicklime (CaO) into a lime slurry using a portable batch slaker* (Fig. 12). With freshly slaked lime slurry the retained heat of hydration will accelerate the lime-soil cementing reaction, which is desirable in cold weather operations.

Water—Slurry water should be clean, fresh and contain no materials deleterious to the lime/soil chemical reactions, such as high acidity, high sulfate content, etc. Lime will readily neutralize acidity, but due to the neutralization reaction, some of the lime will be wasted. The presence of sulfates impedes the lime-silica (pozzolanic) reaction, and when high sulfate water is used to slake quicklime, it vitiates the quality of the resulting lime slurry. For use with lime, the sulfate/sulfite content of the water should not exceed 500 mg/1, and the acidity in the water, as measured by pH, should not be less than 6.5 pH.

In contrast, brackish water and salt-water, high in chloride ions, have been employed successfully in slurry preparation and lime slaking, but its use can cause corrosion of equipment and flash setting.

Surfactant—A wetting agent is commonly used in the lime slurry to reduce surface tension and promote better slurry penetration into the soil mass. A non-toxic surfactant is commonly used and is

*A patent for slaking quicklime and injecting the resulting elevated temperature slurry into the ground is owned by Chemical Lime Company, Ft. Worth, Texas.

added at a rate of approximately one part surfactant to 3500 parts water.

Fly Ash—Fly ash is an artificial pozzolan, collected in electrostatic precipitators from coal combustion systems. The primary ingredient of fly ash is silica which reacts with lime, even under ambient conditions, forming siliceous cementing compounds. A secondary reaction may occur when alumina is present, forming calcium aluminate. Unlike commercial lime with its uniform high quality, fly ash varies considerably in quality, being a by-product material, often inexpensively sold by the producer or supplier. Thus, there are many fly ashes that are low in quality or too marginal for pressure injection without using certain additives to enhance their reactivity. One deleterious impurity, for example, is organic carbon, derived mainly from unburned coal. When the organic content increases to over 5%, it tends to retard the pozzolanic reaction, thus requiring higher percentages of lime and accelerators. Therefore, each fly ash must be tested for its reaction with lime and subsequent durability in the presence of water. Durability is the single most important criterion for evaluating a fly ash source.

LIME STABILIZATION AND LSPI MECHANISMS

The reaction of lime in soil is well established and documented in numerous technical papers (14, 15, 43). Much lime is used today in surface soil stabilization, where it is uniformly spread on a well scarified roadbed at the rate of 3 to 6 percent, by weight of the dry soil. Water is then added and the soil, lime and water are mixed by a disc, rotary, or other suitable mixer. After moist curing for one to five days, the lime treated material is remixed, after which it is compacted with pneumatic-tired, vibratory, or sheepsfoot rollers, and the next layer of base course material or paving surface is placed. Lime may be applied as dry commercial hydrate, dry granular or pebble quicklime, or as a wet slurry of slaked or hydrated lime. (For further information on lime stabilization, see National Lime Association's Bulletin 326, "Lime Stabilization Construction Manual").

The foregoing conventional surface lime stabilization method involves treating a relatively thin layer, 6 to 18 in. thick. For deep-seated problem soils, the use of conventional stabilization would be prohibitively costly since it would require stabilizing multiple lifts or layers of soil.

Conventional surface lime stabilization does not pre-wet the soil deeply as does lime slurry pressure injection. Where used in new construction over plastic clay soils, LSPI actually wets and pre-swells the soil and then tends to retain the high moisture content with its network of lime seams that form moisture resistant barriers.

When expansive clay soils are injected with lime slurry, a number of changes result which together improve the engineering characteristics of the soil mass. These include:

Stabilizing Effect of Lime Seams—The formation of relatively thin lime or lime/fly ash seams (stabilization seams) helps to stabilize the moisture content of the treated soil mass. These stabilization

seams serve as moisture barriers and impede the movement of capillary as well as seasonal moisture through the soil. These seams also help to retain the moisture from the slurry that was injected into the soil. By thus encapsulating large volumes of clay, the volume change potential of the soil is greatly reduced. A significant pozzolanic strength increase occurs at the interface of the stabilization seams and the adjoining clay soil (See Figures 13 and 14).

Preswelling—The soil moisture content is increased approximately 2–3% points following the initial injection and tends to taper off with subsequent injections. Some specifications are written to include achieving a certain moisture content (usually about one half the liquid limit); thus additional injections may be required. It is the opinion of some engineers that the more a soil is preswelled, the less likelihood there is of disruptive swelling after the structure is placed, provided the moisture can be retained in the soil mass below the structure. Preswelling the clay without causing a significant loss in bearing capacity appears to be a residual advantage of LSPI or L/FA injection. Preswelling the clay with water only, on the other hand, may result in unacceptable loss of bearing capacity, and there is no mechanism to cause the moisture level achieved to remain constant.

Translocation—After the stabilization seams are formed, some of the lime translocates (migrates) and modifies the soil adjacent to the seams, resulting in a gradual strength increase. Stocker's diffuse cementation theory suggests that in lime reactive soils, lime pozzolanic reaction products may form in regions of low calcium concentration remote from the lime source (38). It is generally felt that any pozzolanic reaction benefits that result from the injection technique would

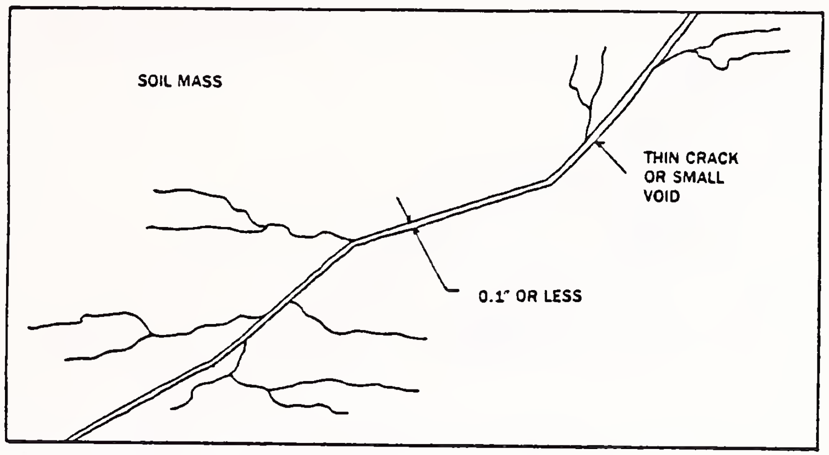


Fig. 13 *In-situ crack before injection*

occur along the lime seams where there is an abundance of calcium to react with the adjacent soils. Blacklock reports that lime glazed samples showed a 60–200% yield strength gain when glazed with 1–1.5% lime to simulate lime seams (6). He states that "the LSPI method of soil stabilization and reinforcement results in the formation of a network of thin sheets and seams. These lime slurry sheets and seams react with the adjacent soil to form strong relatively impervious tensile membranes locked into the soil mass. The effect of these membranes is to control the movement of moisture and to reinforce and confine the segmented portions of the soil mass".

Supernate Penetration—The lime supernate (slurry water) has a pH in the range of 11.9 to 12.4. Thus, when the slurry is injected into the soil and the lime particles are deposited along the fractures as the lime seams are formed, the supernate from the slurry is drawn into the soil between the seams either by soil suction or diffusion mechanisms. It is therefore possible that the soil between the seams will not only be impregnated with slurry water but will have its predominant sodium ions exchanged.

This concept is supportive of Stocker's diffuse cementation theory which explains strength increases with time in the soil mass enclosed in lime seams but not in direct contact with lime particles. Petry's work (31) also evaluated changes that occur in the soil mass between lime seams and concluded that the various injection systems resulted in significant stabilizing water content changes, reduction in plasticity and swelling properties, improve pore water concentrations of calcium between lime seams, and significant soil stabilization against surface movements when exposed to the climate for one year.

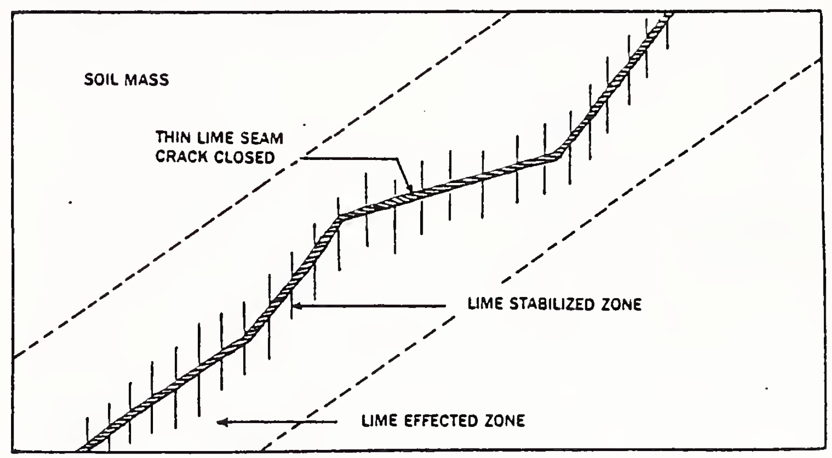


Fig 14 *In-situ crack after lime injection*

Stabilizing Effect of Lime/Fly Ash Seams—Lime/fly ash seams tend to be stronger and thicker than lime seams, providing for most of the stabilizing benefits of lime seams, but also providing stronger compression and shear reinforcement, especially in loosely compacted soils, soils with wide cracks, and soils containing noncohesive aggregate materials (see Figures 15 and 16).

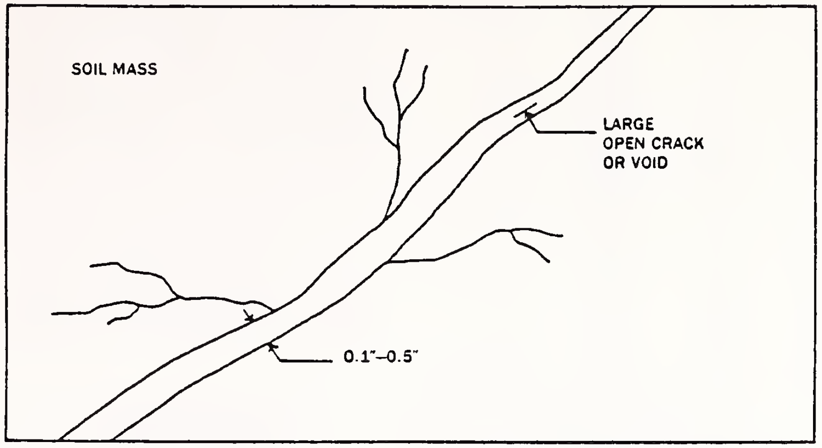


Fig. 15 *In-situ crack before injection*

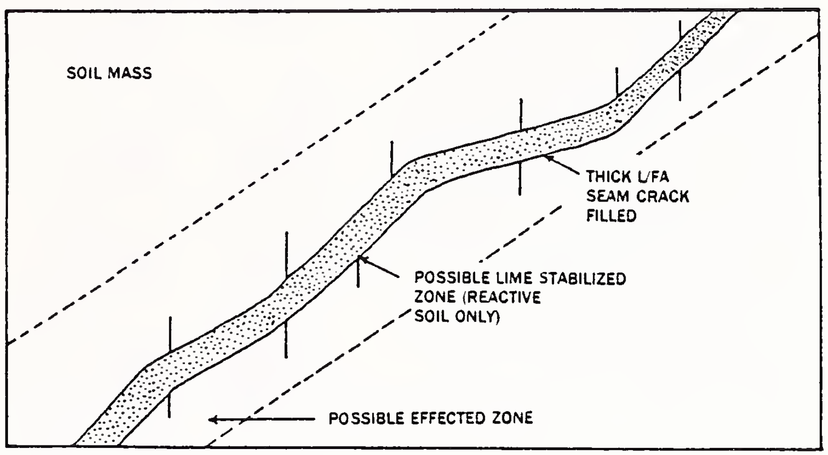


Fig. 16 *In-situ crack after L/FA injection*

EVALUATING CANDIDATE SOIL FOR INJECTION STABILIZATION

The use of standard ASTM soil tests to evaluate potential injection stabilization sites is not recommended. During the past 10 years, LSPI contractors and participating engineers have worked to develop specialized methods for predicting success of potential LSPI sites (5, 6, 7, 9, 13, 18, 25, 41, 42). Some of these tests are modifications of ASTM tests to account for the stabilizing effect of lime seams, and others have been specifically developed for this purpose.

Compression and shear strength tests should be used to evaluate sites with low strength soils; swell tests should be used to evaluate sites with potential settlement problems. Other standard classification tests which give an indirect indication of soil properties such as Atterberg Limits should only be used as preliminary tests or not at all and should never be used in place of strength or volumetric tests.

Lime and Lime/Fly Ash Slurry Soil Testing

Soil testing for lime slurry stabilization is an important part of LSPI technology. The purpose of the testing program is to determine whether LSPI will sufficiently improve the problem soils and to guide in preparing injection specifications. These tests will provide data to help quantify the degree of site improvement that might be expected from injection stabilization; however, it is obviously not possible to obtain a one-to-one correlation between laboratory tests and field results.

Engineers have made a significant contribution to LSPI testing by developing and refining "LSPI evaluation" tests. These test procedures, which simulate the LSPI field conditions, involve treating soil samples with lime slurry to form a glaze or seam, then curing and testing. The results of tests on the glaze or seam lime stabilized test samples are then compared to test values from non-treated control samples. The amount of dry lime solids used in LSPI compatibility testing is usually one percent of the soil dry weight. This has been determined to be the maximum amount of lime injected during a single stage LSPI injection spaced on 5-ft. centers. The laboratory tests can also be used to evaluate the need for a double stage LSPI injection based on injections spaced on 5-ft. centers on a diagonal offset pattern. Laboratory results can then be used as input for preparing appropriate job specifications. All of the recommended "LSPI evaluation" tests are readily adaptable to these situations. Lime glaze or seam stabilized samples can be used in swell, consolidation, and compression testing. This method of sample testing was developed by Woodbine Corp. and Prof. James Blacklock at the University of Arkansas (5, 6, 7, 9, 18, 27). The lime glazed or seam stabilized method can be used with either undisturbed or remolded soil samples, and since the lime treated samples are to be compared to the untreated control samples, both will serve the purpose of evaluating lime/soil reactivity and predicting strength, swell and stiffness improvement.

As with LSPI, the purpose of the L/FA testing program is to determine whether L/FA slurry will sufficiently improve the

candidate site and to guide in preparing appropriate specifications. Although the suggested tests will give data that will indicate the amount of site improvement, it is not possible to obtain an exact correlation between laboratory test results and the precise degree of success obtainable in the field. These test procedures, which attempt to simulate L/FA field results, involve treating soil samples with the L/FA slurry to form seams, then curing and testing. Test results from the L/FA treated samples are compared to the control samples to evaluate the potential benefits of injection stabilization.

The engineering testing program to support LSPI and L/FA injection grouting stabilization currently utilizes several evaluation tests. These tests are described

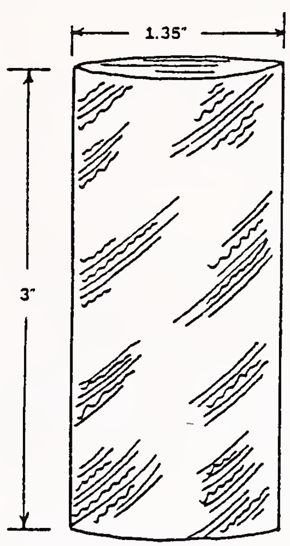


Fig. 17 *Glaze stabilized compression specimen*

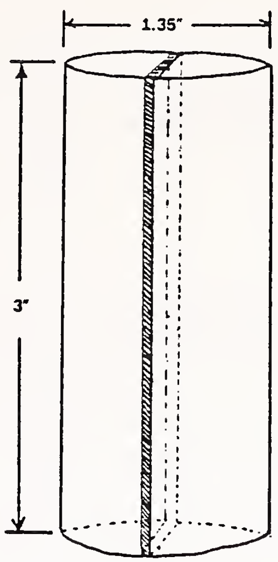


Fig. 18 *Straight seam compression specimen*

in the following paragraphs:*

Glaze Stabilized Compression Test—The glaze stabilized compression specimen is shown in Figure 17. The purpose of the lime or lime/fly ash glaze stabilized compression test is to determine the increase in sample compressive strength from the reinforcement of the glaze stabilized coating. The lime glaze compression test was first reported by Blacklock (6). Samples can be prepared and cured identical to the treated samples.

Seam Stabilized Compression Test—The seam stabilized compression specimens are of two types, 1) straight split seam, (Fig 18) and 2) angle seam (Fig. 19). The straight seam sample is designed for evaluation of the compression strength reinforcement component of the stabilized seam and the angle seam sample is designed for evaluation of the shear reinforcement component of the stabilized seam strength. Typically, the contributions of both compression and shear will be utilized in repairing cracks in pending and existing embankment failures. These samples can be prepared from undisturbed soil samples, but experience indicates a preference for remolded samples. These can also be glaze coated to allow evaluation of combinations of shear, tension and compressive strength reinforcement.

*Details of these test methods are available at the National Lime Association office in Arlington. VA.

Glaze Stabilized Consolidation Test—The glaze stabilized consolidation specimen shown in Fig. 20 is for the purpose of evaluating the settlement improvement provided by injection stabilization of natural embankment soils. This sample is prepared by cutting undisturbed samples and then applying a glaze stabilization coating to both the top and bottom surface of the samples.

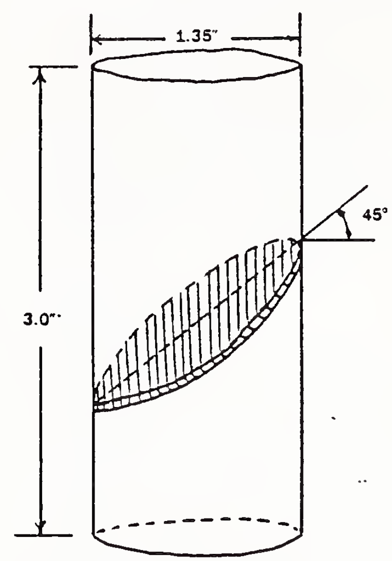


Fig. 19 *Angle seam compression specimen*

Seam Stabilized Swell Test—The seam stabilized swell specimen shown in Fig. 21 is for the purpose of evaluating the swell reduction function of lime or lime/fly ash seams. This sample is prepared by remolding soil and placing a slurry grout seam in the center.

Material Test—In addition to the six soil stabilization tests discussed above, it is also necessary to test all source materials. It is well established that there is a considerable variation in fly ash performance. The seam and glaze tests will help evaluate these performance properties; however, it is always best to evaluate the materials separately by performing a series of cube tests or compression cylinder tests. These tests should evaluate time, temperature and strength variables for different mixing times, different mix ratios and different material manufacturers or sources.

Field Pump Tests—In many instances it may be advantageous to conduct a trial pump test during the design stage to determine the slurry volume placed with a single or double injection. Also it may be desirable to dig a trench to observe slurry flow in the trench side walls, especially if there is a question about available fissures and openings in the soil mass to accept the slurry. This type of data also may be obtained from Shelby tube samples and radiographing them to deter-

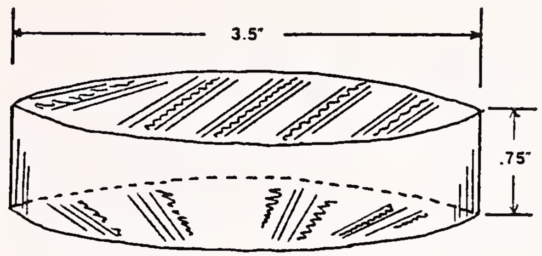


Fig. 20 *Glaze stabilized consolidation specimen*

mine fissures, cracks, and other anomalies that will accept the slurry.

Surcharge Tests—For certain sites where consolidation is the problem, it may be advantageous to inject a test pad and then surcharge the pad as well as a control section and monitor the results. This has been used effectively in evaluating the LSPI and L/FA systems at several sites.

The Decision Process

The ultimate question faced by the engineer who is contemplating the use of LSPI is: Will the injection of lime slurry improve the soil mass, and if so, how much? In compiling the data on which to base the answer to this question, the engineer must consider all of the available data, beginning with the surface exploration of the site and culminating in the evaluation of all the data obtained from the appropriate tests.

In areas such as the Dallas/Fort Worth Metroplex there has been an extensive amount of LSPI stabilization over the past fifteen years (estimated at more than 350 million square feet). This experience provides engineers with a very high confidence level based on the significant empirical evidence of the success of LSPI on their treated areas. Railroads have the unique ability to obtain field results quickly due to continuing train service over treated sections of track.

Interpretation of the data obtained from the appropriate tests is not a simple task because the mechanisms by which LSPI stabilizes the soil are complex. Also, some tests more closely stimulate field conditions than do others. For example, glazed and seam testing of undisturbed samples better simulates the LSPI treatment of the in-situ soil than does remolded samples. Thus strength increases indicated by the addition of lime slurry to remolded samples must by interpreted in conjunction with other data. The existence of fissures and cracks must be considered because it is unlikely that lime slurry will be transported very far into the soil mass if no flow paths exist.

Furthermore, any improvement shown in the tests is only an improvement in the quantities measurable in a laboratory on a laboratory-sized soil sample. The soil sample is not an exact model of the soil mass. For example, the effects of any cracks in the samples do not necessarily duplicate those in the field.

Also, treated samples that show certain improvements will not reveal other possible improvements such as those caused

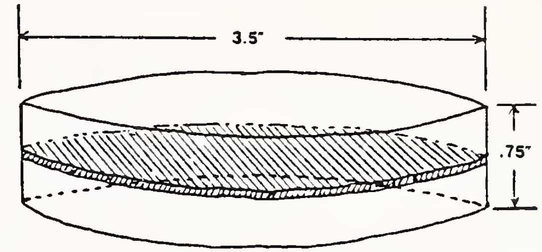


Fig. 21 *Seam stabilized swell specimen*

by moisture stabilization and stoppage of crack growth. Therefore, the results of glazed and seam stabilized tests will generally be conservative.

There is no simple method of obtaining a yes-no answer for all possible LSPI sites; however, the tests and other evaluations outlined in this bulletin will provide meaningful engineering data to aid in the decision process.

LSPI CASE HISTORIES/APPLICATIONS

Since 1960, there have been many interesting as well as large, prestigious projects in which lime or lime/fly ash pressure injection has been used successfully. The following case histories illustrate the versatility of this stabilization technique and, hopefully, will provide ideas for viable solutions to other perplexing construction problems.

Dallas/Ft. Worth Regional Airport

The D/FW regional airport, built in the early 70's, is constructed over a clay formation known as the Eagle Ford shale. This formation is highly expansive and causes extensive damage to buildings and pavement structures if not stabilized or otherwise treated. The terminal buildings, portions of the spine road, hotels, post office and all auxiliary buildings were stabilized using LSPI. Specifications for all of the terminal buildings and most of the other buildings required injections on 5-ft. centers to a depth of 10 ft., followed by injection of water only to achieve a specified moisture content. This stabilization and pre-swelling technique has proven to be very effective in controlling swell and eliminating foundation distress. In all, more than 5 million sq. ft. of foundation area was stabilized at the D/FW regional airport using LSPI.

Railroad Embankment—Chicago & North Western

Typical of many successful projects where LSPI has been used to stabilize high embankments is the Chicago & Northwestern Railroad (C&NW) job near Des Moines, Iowa (33). The embankment consists of 25 ft. of clay fill on about 10 ft.

of clay subgrade that overlays loose to medium, dense sands. Increased rail traffic plus heavier wheel loads caused excessive settlement of the embankment. For years, the fill had defied virtually every maintenance attempt to correct the chronic instability problem (Fig. 22).

Among the remedial methods tried by C&NW, to no avail, were to widen the fill 12 ft. on each side of the ballast section, cement grouting, shallow lime slurry injection that provided temporary improvement for eight months, installation of 10 in. perforated galvanized drain pipe and adding riprap at the toe of the slope. Over a seven year period about 200 railcars of aggregate were added to the badly subsided areas of the fill, resulting in 8 to 10 ft. deep ballast pockets. The weight of the ballast on the soft clay fill and subgrade tended to push out the base, resulting in bulges at the toe of the slope 35–40 ft. out from the centerline of the rails. It was not uncommon for the track to be out of cross level 3 to 4 in. when a train would pass at 5–10 mph.

In addition to excessive maintenance expense over six years, C&NW was burdened with a slow order of 5–10 mph over this short stretch of unstable embankment. In the summer of 1976, the railroad decided to stabilize this problem area by using lime slurry pressure injection in three stages since tests showed a good lime-clay reaction.

In the first two stages lime slurry was injected to 14-ft. depth in three simultaneous injections, with a 2–3 day curing period in between; in the second stage injections were made between the first injections. The third stage was a single penetration to 40-ft. depth just inside one of the rails every 10 ft. On traversing the 1000 ft. rail line, the equipment returned injecting just inside the other rail, but beginning the injections 5 ft. from the last injection (inside the other rail). Thus, a 40-ft. injection was made diagonally across the track every 5 ft. (Fig. 23)

More than 300 tons of lime were required on this 1000-ft. stretch of track. The 40-ft. injections averaged about one

Fig. 22 High railroad embankment (C&NW)

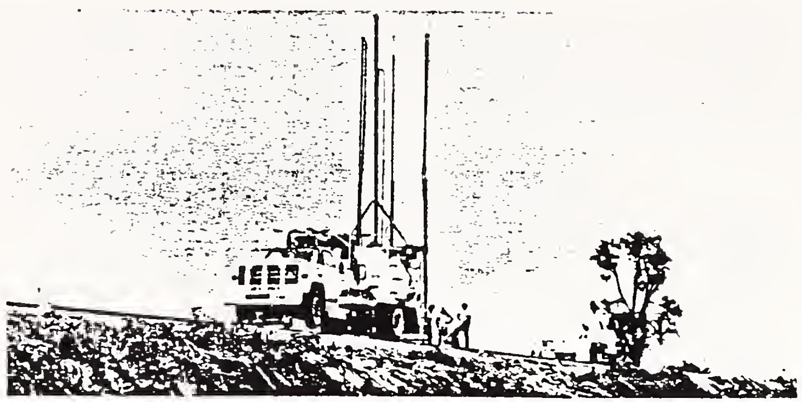


Fig. 23 "First" 40-ft LSPI rig on railroad job

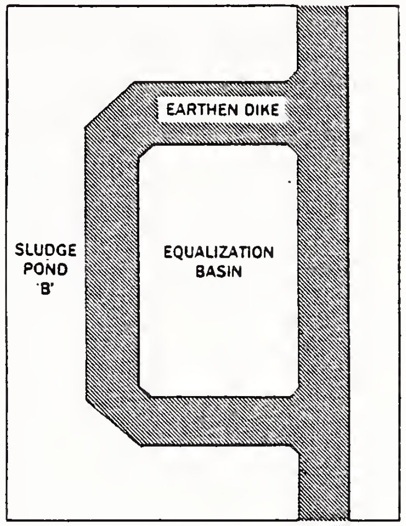


Fig 24 Diagram of equilization basin on Lion Oil Co. job

ton of lime per hole. During the 14-ft. injections, the injected slurry forced free water out of the fill into ditches along either side for the embankment. Three weeks after the project was completed, the railroad was able to return to timetable speed of 49 mph; settlement was arrested due to strengthening the fill and subgrade. Since 1976, maintenance on this track has been minimal.

Dike Stabilization— Lion Oil Co.

In a plant improvement project designed to reduce high maintenance of the Lion Oil Company's sludge lagoon and stabilization basin at El Dorado, Ark. it was deemed necessary to strengthen an earthen dam that separated the equalization basin from the sludge pond, as depicted in Fig. 24. The desired im-

provement required draining the 10 ft. deep equalization basin, reshaping the earthen dam and gunniting the free basin. The saturated earth dike was so weak that on draining they feared it would collapse because of the lateral pressure of the adjacent sludge lagoon. Test borings revealed a sandy clay with 25% average moisture content and an average cohesive shear strength of only 0.07 ton/sq. ft.

It was decided to strengthen the dike with a three stage lime and lime/fly ash pressure injection program (46). Such a treatment would also reduce the mass permeability of the dike fill (Fig. 25).

The injection plan comprised:

Stage 1—Four simultaneous lime slurry injections, 10 ft. deep, on 5-ft. centers around the dike, traversing 600 lineal ft.

Stage 2—Lime/fly ash slurry injections, 10 ft. deep, spaced diagonally between Stage 1 injections.

Stage 3—Lime slurry injections, same as Stage 1 and spaced between previous injections.

Soil tests made three weeks after completion of injections revealed that N-values and cohesive shear strengths of the treated soil increased an average four-fold and six-fold, respectively, from the untreated soil, even though the dike contained about the same (or 2% more) moisture than before treatment. On draining the basin and dredging and reshaping it after 5 weeks of curing, there was no seepage through the basin's sidewalls, and the dike withstood the lateral pressure from the lagoon and supported a 75-ton-rubber-tired clamshell used to excavate the basin.

Landfill Stabilization—Saving a Commercial Building

A 20,000 sq. ft. commercial building was constructed in 1968 in an area of Fort Worth, Tex. that was previously used as a sanitary landfill. Depth of the landfill varied from 8 to 10 ft. below the building. The foundation structure of this building consisted of piers that extended below the landfill into the natural subgrade. As a

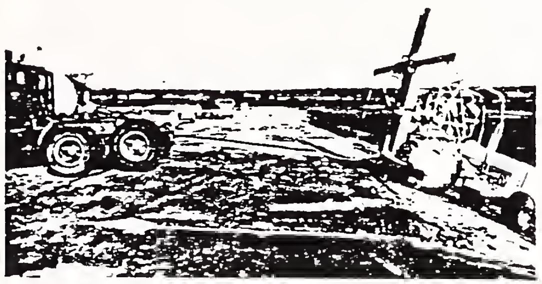


Fig 25 *Injector on dike stabilization project*

result, the exterior walls were in satisfactory condition; however, the floor slab had been poured on grade and had settled as much as 14 in., resulting in the owner's loss of all commercial tenants except one.

After studying various solutions to his problem, the owner opted on a program of lime/fly ash pressure injection grouting as the only economically feasible method to salvage his building for beneficial use. The remedial work was accomplished in three phases as follows:

Phase 1—Curtain injection was first performed around the building perimeter on 5-ft. centers to a depth of 10 ft. A second series of injections were made between each of the first injections, but set back 5 ft. from the wall. The object of phase 1 was to create a grout curtain to help contain subsequent injections within the building area.

Phase 2—Holes were drilled through the concrete floor slab on 10-ft. centers and the entire area grouted with lime/fly ash slurry. A grout mixture of 5 lb. dry solids/gal. water was used. Pressure injection was done until refusal which could be observed visually in the adjacent holes since there was a 6 to 8 in. void below the floor slab. In some instances slurry flow was observed 20 ft. away from the injection holes. In the early stages of grouting, methane gas issued from the grout pipes, which on ignition resulted in flares 2 to 3 ft. long. As grouting progressed, the methane flares were reduced until finally no ignition was possible.

Phase 3—Lastly, a heavier grout of 6 lb. solids per gal. was pumped between the floor slab and stabilized subgrade to fill this void and to elevate (by hydraulic pressure) the slab to its original configuration level. Results: The floor slab has resisted settlement for more than five years since project completion, and methane gas leakage has not recurred. The building is now fully occupied.

Dewatering Project—Dow Chemical Co.

In 1975 a combination lime and lime/fly ash injection project was completed for Dow Chemical Co., Freeport, Tex. In order to construct four 120 ft. concrete filtering tanks, it was necessary to excavate a 350 ft. × 350 ft. area to a depth of 15 ft. below sea level. Initial efforts at excavation were thwarted due to almost immediate ground water infiltration. A geotechnical firm was hired by Dow to study the problem. They concluded that the cause of the excessive water was a 6 to 12 in. sand lens that varied in depth 6 to 8 ft., which was piping water from a nearby river.

Due to the high cost of using sheet piling, the company decided to evaluate other methods for dewatering. A combination system of lime and lime/fly ash slurry injection was chosen because of the substantial cost savings. Initial injections were made on 5-ft. centers to a depth of 10 ft. using lime slurry. After a curing period of 48 hr., a second injection series was made in two orthogonal directions between the initial injections (a 2½-ft. grid). The second injection series consisted of a lime/fly ash slurry of 1 lb. lime to 2 lb. fly ash as dry solids per gallon water. These injections were made around a 75 ft. perimeter berm.

The entire area was injected to add strength to the saturated silty clay soils to

help support the clamshell cranes during excavation. The second lime/fly ash injections around the perimeter were designed to shut off the flow of water into the sand seam.

After a 10 day curing period following the injection, excavation was resumed, and the contractor was able to control the leakage of a small amount of water with two small gasoline-powered pumps. The project manager reported the pressure injection option saved $75,000. Based on this success, Dow later used LSPI to stabilize several miles of their railroad subgrade.

Stopping Methane Gas and Leveling Slab-on-Grade

A 52,500 sq. ft. building in Mesquite, Tex., which had been constructed over an old sanitary landfill, was subsequently condemned by the fire marshall due to excessive methane gas inside the building. The building was vacated and had become a total economic loss to the owner. The owner attempted to evacuate the methane gas by installing a series of pipes throughout the building with the pipes extending through the floor slab into the landfill and up through the roof. Blowers were used to force the gas out through the pipes (Fig. 26). Another series of pipes was used at the exterior perimeter of the building (Fig. 27). This system did not remove the gas, and the owner was still unable to lease the building.

A decision was made to use lime/fly ash injection to neutralize and shut-off the methane gas. Also, the floor slab had settled approximately 2½ in. in some areas, and lime/fly ash grout was used for releveling.

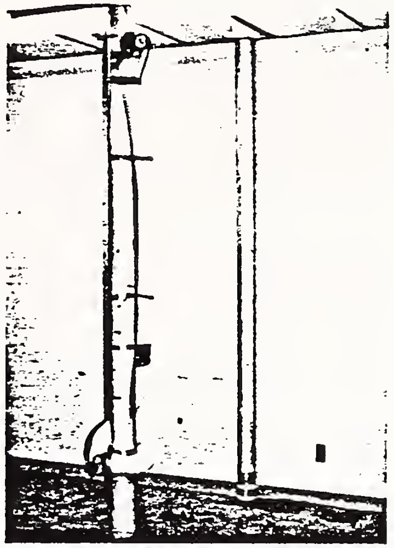


Fig. 26 *Methane blowers and pipes used in basement over landfill*

Work was accomplished on about 30,000 sq. ft. of the building as follows:

1. Holes were drilled through the floor slab on 10-ft. centers.
2. Lime-fly ash grout of 2 lb. each of lime and fly ash to 1 gal. water was pressure injected into the subgrade to an average depth of 9 ft. Grouting started first along the exterior walls to form a curtain to contain subsequent grouting within the building's confines. Grout pipes were inserted in each hole and forced to the bottom of the landfill or until impenetrable material was encountered. Lime-fly ash grout was pumped to refusal at 100 psi pressure. Grout pipes were then gradually raised to intermediate levels with the same process repeated.

Fig. 27 *Methane gas evacuation pipes used prior to injection*

3. The leveling and sealing operation followed. A slurry mixture of 2 lb. lime and 4 lb. fly ash to 1 gal. water was injected below the floor slab to relevel the distressed slab and finally to fill any remaining voids over the whole floor area.

The fire marshall made periodic checks for methane gas as the work progressed until no trace of gas could be detected. The building was leased to a new tenant, and occupied in 1983. No methane gas evolvement has recurred for three years.

Strengthening the Subgrade—Industrial Complex in Ohio

Builders of a large industrial building planned for construction in Ohio were faced with a problem subgrade soil at a low-lying 17-acre site. A railroad spur and work yard were also planned. The subgrade soils varied widely, and included layers of silt, loam, gravel, and medium to heavy clays. Due to its low-lying position with poor drainage, the site was saturated with moisture, up to the average plastic limit of the soil or slightly over. Floor loads up to 4,000 psf had to be accommodated. Trafficability at the site was poor even when the ground was partially frozen. When soil borings were taken, water entered the holes at 10 to 15 ft. and rose to within 0 to 5 ft. of the ground surface after some hours of drilling. Soil tests indicated the differential settlements of 1½ to 1 in. would occur under the proposed floor use, which was unacceptable. The high water table precluded over-excavation and recompaction of the soil. So it was decided to lime pressure inject all of the in-situ soils on the site covering the building, rail spur and yard.

Tests indicated that lime reduced the Plasticity Index of the fine-grained soils from a high of 34 to a low 9. Yet strength tests indicated relatively little improvement with lime, but in spite of this it was decided to pressure inject since lime has been successful with other similar type soils.

All in-situ soils were injected to 10 ft. depths on 5-ft. centers to refusal with lime slurry. The excess slurry that was ejected at the surface around the injection pipes and fracture cracks was mixed with

the top 6 in. of soil and compacted, forming a working table that aided trafficability. Survey points were established prior to injection to observe possible surface movements due to pressure injection. In a few areas the surface heaved as much as 6 in., indicating hydraulic fracturing of the soil at shallow depth. Free water flowed through cracks and crevices, being displaced by the lime slurry. Little or no settlement has occurred for three years. N-values from standard penetrometer tests ranged between 10–16 blows/foot against 5–11 blows before injection.

Landfill Stabilization for Parking Lot Construction

The city of Dallas recently completed a sanitary landfill, and since the land is in a very desirable area, it was purchased for industrial development. The developer excavated the landfill material below the streets and replaced it with suitable clay fill. Then as buildings are constructed, the procedure has been to excavate the landfill (approximately 10 ft. deep) and replace it with suitable borrow material. Because this is a very expensive procedure, the owner of this project decided to investigate alternate procedures to reduce the cost of installing the parking lot which covered 25,000 sq. ft.

Lime/fly ash injection was selected by the owner's consulting geotechnical engineer. Injections were completed in two stages, using a tractor-mounted injection unit. The first injections were made on 5-ft. centers to a depth of 10 ft. Secondary injections were then made diagonally between the first injections. Slurry was mixed at the ratio of 1 lb. lime and 3 lb. fly ash per gal. of water, and all injections were continued to refusal.

At the beginning of the project, a backhoe was utilized to open a ditch to allow visual inspection of the flow of slurry through the landfill. The experiment confirmed that the slurry was able to flow freely through the landfill material (Fig. 28).

Additional field investigation consisted of installing three percolation test holes before injection and three following injection to evaluate penetration of the lime/fly ash slurry through the landfill material. The test results indicated a decrease in percolation rate from 3 to 20 times after the injection was completed.

Fig. 28 Lime/fly ash inspection trench in stabilized landfill pavement

The parking lot was paved with a 4-in. reinforced concrete slab, and visual inspection after three years of service shows no distress to the structure (Fig. 29).

Parking Lot Stabilization—Dallas/Fort Worth

Many areas in the Dallas/Fort Worth Metroplex and throughout the U.S. are plagued by failures of pavement surfaces, both in parking lots (Fig. 30), and on widely traveled streets and roads. Most of these failures are the result of disruptive swelling from the deep layers of expansive clays in the area. Some of the characteristics of pavement failure due to expansive clays are potholes, alligator cracking, (Fig. 31), and the most distinguishing which is a wave-type form of failure in which the pavement becomes a series of rolling dips and peaks in rapid succession. Once a failure occurs and there is surface cracking, then more rapid deterioration results as surface water is fed directly to the underlying clays. For many years the standard procedure for treating areas to be paved has been to use conventional lime stabilization to create a stabilized layer at the surface (usually 6–8 in. thick) and then to place the pavement directly on the stabilized layer. Because this thin stabilized layer may not be adequate to cope with the deep clay layers in certain areas, the use of pressure injection has grown significantly in recent years. Injections are normally made to depths of 3–5 ft., with 4 ft. being the most common. For sites with highly active clays or where heavy wheel loads are anticipated, a second injection is recommended. After completion of injection, the surface lime is mixed into the top 6 in. so the end result is a combination of the benefits of deeper stabilization plus surface treatment. In many instances 4 ft. injection stabilization can be done for less money than a 6–8 in. conventional stabilization job, and while a double 4 ft. injection job may have a slightly higher

Fig. 29 Parking lot pavement over stabilized landfill

Fig 30 *Parking lot failure on "grand opening" day*

initial cost the future savings in maintenance and repair should be substantial and the benefits appear obvious.

Developing Applications for Pressure Injection

From the foregoing case histories which represent only a fraction of the accumulated LSPI experience, it is apparent that lime and lime-fly ash pressure injection is a steadily expanding approach to soil stabilization for both preventative and remedial purposes. The diversity of applications to date include building foundations, railroad beds, highways, slopes, levees, runways, parking lots, dikes, storage tanks, and landfills as well as dewatering and acid neutralization. LSPI can be used to reduce potential volume change in soils, increase strength and bearing value, stabilize moisture content, drive out excessive free ground moisture, impede seepage and flow of water or leachates, stop methane gas evolvement from landfills, fill voids, and densify and consolidate.

Fig. 31 *Parking lot alligator cracks require frequent expensive repairs*

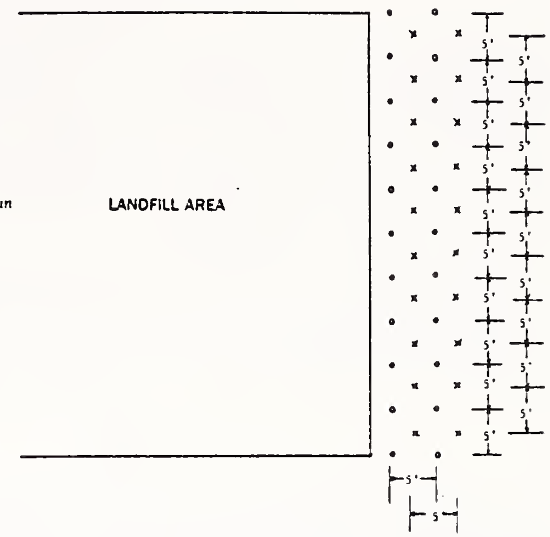


Fig 32 *Diagram of injected curtain wall around landfill*

Based on experience to date it is believed that LSPI or L/FA has much potential as an economic method of treating active or abandoned landfills. Today there is much concern over toxic leachates contaminating ground water aquifers, and it appears that LSPI would be a

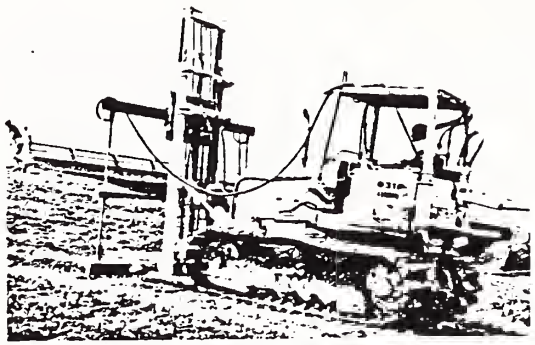


Fig 33 *Lime/fly ash injector on highway embankment*

major weapon for protecting ground water, neutralizing leachate plumes in sanitary landfills and for placing curtain walls for preventing leachate migration (Fig. 32).

New excavated areas for planned landfills can be stabilized by lime or lime/fly ash pressure injection as a construction technique to impede the leaching of potential toxic compounds into the ground water.

Another promising field of application for pressure injection is in the treatment of toxic wastes. Lime is well known for its ability to "fix" heavy metals, and the high alkaline environment made possible by injecting lime slurry can inhibit mobilization of heavy metals and other contaminants. A recent evaluation of various methods of remedial action of uranium mill tailings concluded that L/FA injection may offer a viable solution (39).

Lime slurry pressure injection stabilization of existing highways is an area where the experiences gained in stabilizing railroads can be directly correlated to the highway system. Where deep, unstable soil conditions cause surface distortion and produce undesirable ride characteristics, LSPI stabilization may be appropriate before placing the overlay. Injections may be done through holes drilled in the pavement or at the edge of the shoulder to form a curtain wall to prevent moisture fluctuation below the slab.

Also, LSPI offers an economically feasible method to stabilize surface slides and slope failures which have long plagued highway agencies. Two FHWA demonstration projects were installed in the summer of 1983 in Arkansas (1) and in Alabama (7) (Fig. 33) and one in Missouri in 1984.

A demonstration project was also carried out during the spring of 1984 by the Texas Highway Department near Greenville, Tex., where sections of injected curtain wall were used to extend the useful life of the overlay. Other projects are in various stages of planning with highway departments, and it appears that LSPI can play a vital role in the rehabilitation of the highway system.

SAFETY PRECAUTIONS

Hydrated lime (calcium hydroxide), like most materials or chemicals in common use, is not dangerous to work with provided that precautions are exercised. While the danger of severe skin burns caused by lime is remote, it generally is desirable to prevent hydrated lime from coming into contact with a worker's skin. Prolonged contact of hydrated lime with skin damp with perspiration and chafed by tight clothing can produce burns. Thus, particular care must be taken to avoid the presence of lime slurry inside shoes or boots. Hot, humid weather tends to heighten the caustic effect of hydrated lime on the worker's skin. Also, persons with particularly sensitive skin have developed forms of skin irritation through prolonged contact. There is no urgency in removing hydrated lime dust from open skin areas, but it should be flushed off with water as soon as convenient.

If the following recommendations are followed, there is little possibility that workers will suffer skin burns or irritation. In a closed mixing system, the dangers from lime dust are avoided, and dust-related precautions are not necessary except during the transfer operation, when the workers should exercise care in protecting their eyes.

Eye Protection—Although goggles or safety glasses with side shields are recommended while working with lime, they are seldom worn by injection workers. It is important, therefore, that the contractor has eyewash kits readily available in the event of a hose break or other occurrence causing lime slurry to be sprayed into the worker's eyes. This is the most common cause of worker injury, and eye damage can be caused if the worker rubs the eye which has been sprayed with lime or if it is not washed immediately.

Skin Protection—Workers should bathe or shower after a workday to cleanse the body entirely of lime. When necessary, a solution of vinegar applied to the hands, feet, or other nonsensitive body parts will neutralize any lime which remains on the body after washing.

FIRST AID

Skin Burns—Wash thoroughly with soap and warm water and vinegar to remove all lime. Apply a standard burn ointment used for heat or caustic burns and cover with sterile bandages. Keep bandaged during healing to prevent infection.

Lime in the eyes—DO NOT RUB THE EYE! Hold worker's eye open and flush with water immediately. Eye-wash kits should be carried on each vehicle. Report all serious burns from lime or cases of lime in eyes immediately so that medical attention can be provided if necessary.

GENERAL PRECAUTIONS

Generally, the workers most vulnerable to lime dust burns and the ones who should practice rigorously the above precautions are those handling bagged lime and those operating bulk-transfer equipment. In general, greater care should be exercised in bag applications than in bulk. Since the greatest danger is to the eyes, all workers emptying bags of lime must be equipped with close-fitting goggles. If a worker in a bent-over position should drop an open bag on the ground, the impact could cause a dense cloud of lime dust to arise directly into the worker's face. If his eyes are unprotected by goggles, loss of sight might result from lime burns. Workers in the vicinity of dry lime transfer and mixing operations should wear goggles to prevent a blast of lime dust from hitting their eyes.

The least hazard from the lime burns is encountered in handling the lime slurry. Only workers with unusually sensitive skins are adversely affected by slurry splashing on their bare skin. But the same rigid care should be exercised to prevent

lime slurry from getting into the eyes and shoes or soaked into clothing.

The above precautions are largely intended for contractors who are using lime for the first time. Contractors experienced with lime have learned to deal with these safety practices. However, "an ounce of prevention" is important, so all contractors should carefully brief each worker, inspector, and others at the job site on lime precautions and, most important, check to see that the worker abides by these few simple safety rules. Practically speaking, hydrated lime or slurry is no more dangerous to the skin than portland cement; lime is simply lighter and finer than cement and more prone to blow. Because the slurry is under high pressure, there is an added element of danger due to possible hose breaks.

CONCLUSIONS

Important to the understanding and success of any LSPI job is determination of the presence of adequate fissures, openings and soil anomalies to allow lime slurry penetration through the mass. Many engineers who have limited experience with LSPI are often dubious that slurry can penetrate highly plastic "impervious" clays. This is generally based on the extremely small size of clay particles and the fact that lime and lime/fly ash slurries are essentially suspension grouts as opposed to true chemical (solution) grouts.

Experience has shown, however, that nearly all expansive clays can be injected

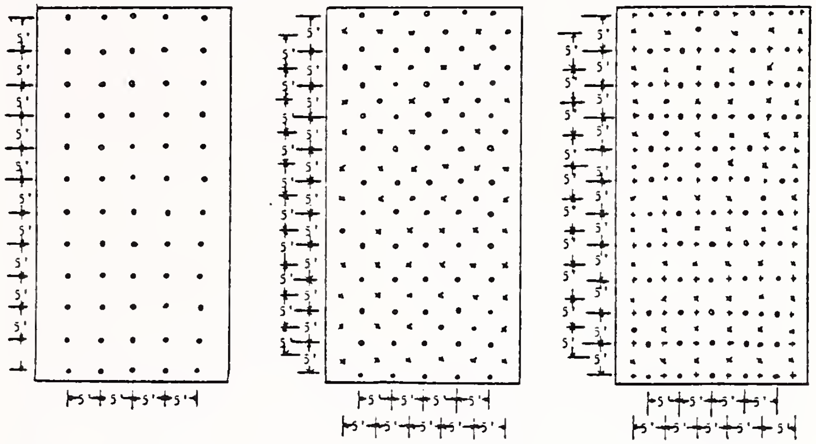


Fig. 34 *Diagram of three common injection plans*

since there appears always to be dessication cracks and fissures through which the slurry can flow. Even the infamous Yazoo clay of Mississippi has been successfully injected.

Even when clays are wet, the fissures are still present due to soil being a nonelastic system (once a crack develops, it appears to remain). Fewer fissures and "tighter" more plastic clays usually indicate that closer spacings and more than one injection pass will be required. In the early days of LSPI a single injection to refusal on 5-ft. centers was considered adequate and was routinely performed on all problem soils. Now it is common to use multiple injections, closer spacings and a combination of materials designed to meet the needs of a specific site. Figure 34 shows several different injection plans commonly used for expansive clay soils.

Over the past twenty years LSPI has grown from a fledgling system based on utilizing rather crude hand injections, to its present status as a well accepted, growing industry with automated equipment capable of 40 ft. deep penetration for a multiplicity of applications (Fig. 35).

Considerable research over the years has added to the body of knowledge about LSPI. Additional technical breakthroughs that will allow for better, more reliable testing appear imminent based on current work. The increased use of low cost additives such as fly ash promises to continue. Almost without exception, use of Lime Slurry Pressure Injection will result in substantial cost savings, assuring a continuing future for this stabilization technique.

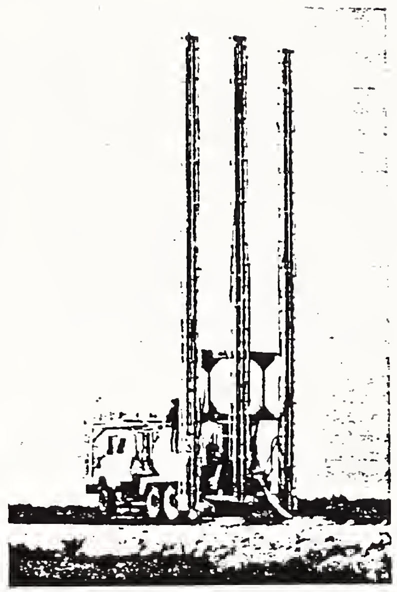


Fig. 35 *New forty foot injection truck built for railroad stabilization*

BIBLIOGRAPHY

1. Arkansas Highway and Transportation Department, Materials and Research Division, "Demonstration Project No. 59: Lime-Fly Ash Slope Stabilization, West Memphis, Arkansas," Arkansas State Highway and Transportation Department, Little Rock, Ark., January, 1984.

2. Barenberg, Ernest J., "Lime or Cement Fly Ash—Aggregate Pavements," University of Illinois, March, 1977.

3. Blacklock, James R., "Evaluation of Railroad Lime Slurry Stabilization," Federal Railroad Administration, Final Report, FRA/ORD-78/09, June, 1978.

4. Blacklock, James R., Joshi, R.C., and Wright, Paul J., "Pressure Injection Grouting of Landfills Using Lime and Fly Ash," Proceedings—ASCE Speciality Conference, Grouting in Geotechnical Engineering, New Orleans, La., February, 1982.

5. Blacklock, J.R. and Lawson, C.H., "Handbook for Railroad Track Stabilization Using Lime Slurry Pressure Injection," Federal Railroad Administration Report No. FRA/ORD-77/30, June, 1977.

6. Blacklock, James R., "Lime Glaze Method of Soil Testing," Proceedings—Grouting in Geotechnical Engineering, ASCE Specialty Conference, New Orleans, Louisiana, February, 1982.

7. Blacklock, J.R., and Wright, P.J., "Injection Grouting Restoration of Failed Highway Embankment Slopes," 65th Annual Transportation Research Board, Washington, D.C., January 1986.

8. Blacklock, James R., and Wright, Paul J., "Stabilization of Landfills, Railroad Beds and Earth Embankments By Pressure Injection of Lime/Fly Ash Slurry," Conference Proceedings—Ash Tech '84, Second International Conference on Ash Technology and Marketing, London, England, September, 1984.

9. Blenden, Robert E., "A Study on the Effects of a Saturated Solution from Lime Slurry on the Strength of a South Dakota Clay," Masters Thesis, University of Arkansas Graduate Training Institute of Technology, Little Rock, Arkansas, 1977.

10. Building Research Advisory Board, "Chemical Soil Stabilization," National Academy of Sciences, Washington, D.C., 1969.

11. Chang, David Ta-Teh, "Short Term Property Changes of an Active Clay Soil Caused by Injection of Lime and Fly Ash," Masters Thesis, University of Texas at Arlington, Arlington, Tex., 1981.

12. Cothren, S.M., "Roadbed Stabilization by Lime Slurry Injection Process," *Fifth International Conference on Expansive Soils*, Adelaide, South Australia, May, 1984.

13. Eades, J.L., Grim, R.E. "A Quick Test to Determine Lime Requirements for Soil Stabilization," Highway Research Record No. 139, pp. 61–72, 1966.

14. Eades, J.L., Grim, R.E. "Reactions of Hydrated Lime with Pure Clay Minerals in Soil Stabilization," Highway Research Board Bulletin 262, 1960.

15. Eades, J.L., Nichols, F.P., and Grim, R.E. "Formation of New Minerals with Lime Stabilization as Proven by Field Experiments in Virginia," Highway Research Board Bulletin, 335, pp. 31–39, 1962.

16. Farris, J.B., "Lime Injected Roadbed Stabilization Project Experiences," Proceedings of Roadbed Stabilization Lime Injection Conference, August, 1975, FRA-OR&D-76-137, November, 1975.

17. Fohs, D.G., and Kinter, E.B., "Migration of Lime in Compacted Soil," Public Roads, 37, No. 1, June, 1972.

18. Greeson, William C., "Laboratory Testing of Lime Slurry Pressure Injected Soils," Masters Thesis, University of Arkansas, Fayetteville, Arkansas, 1975.

19. Higgins, C.M., "High Pressure Lime Injection," Research Report No. 17, Interim Report No. 2, Research Project No. 63-7S, Louisiana Department of Highways, August, 1965.

20. Higgins, C.M., "Lime Treatment at Depth," Reseach Report No. 41, Final Report, Research Project No. 63-7S, Louisiana Department of Highways, June, 1969.

21. Holtz, W.G., "Volume Change in Expansive Soils and Control by Lime Treatment," Proceedings, Second International Research and Engineering Conference on Expansive Clay Soils, Texas A&M University, College Station, Tex., 1969.

22. Ingles, O.G., & Neil, R.C., "Lime Grout Penetration and Associated Moisture Movements in Soil," Research Paper No. 138, Division of Applied Geo-mechanics, C.S.I.R.O., Australia, 1970.

23. Ingles, O.G., "Soil Stabilization. The Next One Hundred Years," Symposium on Soil Reinforcing and Stabilizing Techniques, Sydney, Australia, 1978.

24. Jones, D. Earl, "Expansive Soils and Housing Developments," Presented to the Workshop on Expansive Clays and Shales in Highway Design, Denver, Col., December, 1972.

25. Joshi, R.C., and Wright, P.J., "In-Situ Soil Improvement by Lime and Lime Fly Ash Slurry Injection Process," Symposium on Soil Reinforcing and Stabilizing Techniques in Engineering Practice, Sidney, Australia, 1978.

26. Lai, T.M., and Mortland, M.M., "Self Diffusion of Exchangeable Cations in Bentonite," Proc. 9th National Conference on Clay and Clay Minerals, Vol. 9, pp. 229–247, 1960.

27. Lawson, Chris H., "A Study of the Effect of a Lime Seam on the Unconfined Compression Characteristics of a South Dakota Clay," Masters Thesis, University of Arkansas Graduate Institute of Technology, Little Rock, Ark., 1977.

28. Lundy, H.L. Jr., and Greenfield, B.J., "Evaluation of Deep In-Situ Soil Stabilization by High-Pressure Lime-Slurry Injection," Highway Research Record No. 235, Highway Research Board, 1968.

29. McKeen, R. Gordon, "Design of Airport Pavements for Expansive Soils," Federal Aviation Administration Report No. FAA-ARD-830, January, 1981.

30. National Lime Association, "Lime Stabilization Construction Manual, Bulletin 326, Arlington, Va., 1982.

31. Petry, Thomas M., et al, "Short Term Active Soil Property Changes Caused by Injection of Lime and Fly Ash," Proc., Transportation Research Board, Washington, D.C., 1982.

32. Petry, T.M., and Armstrong, J.C., "Relationships and Variations of Properties of Clay," Proceedings of the Fourth International Conference on Expansive Soils, Volume 1, Sponsored by ASCE, Denver, Colo., June, 1980.

33. Progressive Railroading, "C&NW Goes Deep With Lime," October, 1976.

34. Progressive Railroading, "Lime Does Job for MoPac," September, 1978.

35. Progressive Railroading, "Yazoo Clay into Stable Roadway," April, 1978.

36. Railway Track & Structures, "Roadbed Stabilization by Lime Slurry Injection," June, 1975.

37. Robnett, Quentin L., "Alteration of Soil Properties as Effected by Various Lime Treatment Procedures," Proceedings of Roadbed Stabilization Lime Injection Conference, August, 1975, FRA-OR&D-76-137, November, 1975.

38. Stocker, P.T., "Diffusion and Diffuse Cementation in Lime and Cement Stabilized Clavey Soils," Special Report No. 8, Australian Road Research Board, 1972.

39. Tamura, T. and Boegly, W.J., Jr., "In Situ Grouting of Uranium Mill Piles: An Assessment," Oak Ridge National Laboratory, ORNL/TM-8539, May, 1983.

40. Townsend, Frank C., and Donaghe, Robert T., "Investigation of Accelerated Curing of Soil-Lime and Lime-Flyash-Aggregate Mixtures," Technical Report S-76-9. Soils and Pavements Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, August, 1976.

41. Thompson, Marshall R., "Field Evaluation of Pressure Injection Lime Treatment for Strengthening Subgrade Soils," Proceedings of Roadbed Stabilization Lime Injection Conference, August, 1975, FRA-OR&D-76-137, November, 1975.

42. Thompson, M.R., and Robnett, Q.L., "Pressure Injection Lime Treatment of Swelling Soils," Presented at Transportation Research Board 54th Annual Meeting, Washington, D.C., January, 1975.

43. Transportation Research Board Committee on Lime and Lime-Fly Ash Stabilization, "State of the Art: Lime Stabilization," Transportation Research Circular No. 180, September, 1976.

44. Transportation Research Board, "Lime-Fly Ash-Stabilized Bases and Subbases," NCHRP Synthesis of Highway Practice No. 37, 1976.

45. Vickers, Albert F., "Environmental Considerations," Proceedings of Roadbed Stabilization Lime Injection Conferences, August, 1975, FRA-OR&D-76-137, November, 1975.

46. Woodbine Corporation, "Stabilization of Equalization Basin Dike," Case History D76-24, Fort Worth, Tex., December, 1976.

47. Wright, Paul J., "Lime Slurry Injection Tames Expansive Clays," Civil Engineering—ASCE, 43, October, 1973.

48. Wright, Paul J., "Lime Injection Production Equipment and Techniques," Proceedings of Roadbed Stabilization Lime Injection Conference, August, 1975, FRA-OR&D-76-137, November, 1975.

49. Wright, Paul J., "Lime/Fly Ash Injection Applications," presented at the February 25–27, 1979, 5th International Ash Utilization Symposium held at Atlanta, Ga.

50. Wright, Paul J., "Lime/Fly Ash Injection Stabilization," presented at the October 22–27, 1978, Conference on Ash Technology and Marketing held at London, England.

51. Roads & Streets, "Deep Lime Injection Stabilizes Mall Site," August, 1975.

ABOUT THE PUBLISHER OF THIS BULLETIN—

National Lime Association is the trade association for manufacturers of commercial quicklime and hydrated lime. Among its most important functions are the education of the consuming public as to the most efficient application of lime, as well as publishing general technical information in those fields where lime is used.

In the highway field, lime has grown to be a major construction material within only a few decades. Because of this rapid growth, the association has devoted much of its effort on research and market developments in lime stabilization.

Among its publications of interest to the engineering profession are:

1. "Lime Stabilization Construction Manual," Bulletin 326, 1982.
2. "Use of Hydrated Lime in Asphalt Paving," Bulletin 325, 1984.
3. "Flexible Pavement Design Guide," Bulletin 327, 1972.
4. "A Long Range Durability Study of Lime-Stabilized Bases," Bulletin 328, 1977.
5. "Lime Stabilization Under Hydraulic Conditions," 1978.
6. "Lime Dries Up Mud," Brochure, 1981.
7. "Lime Handling, Application, and Storage," Bulletin 213, 1982.
8. Numerous technical reprints on lime stabilization.

In addition, National Lime Association has produced the following 16 mm. sound-color movies, which are available on a free loan basis to interested highway groups and engineering schools in North America.

1. "Lime—The Versatile Stabilizer in Construction," 1982, 26 min.
2. "World's Largest Lime Stabilization Project—Dallas/Ft. Worth Airport," 1973, 18 min.
3. "Irrigation Canal Stabilized with Lime," 1974, 15 min.
4. "River Levee Stabilized with Lime," 1975, 18 min.

For further information, write:

NATIONAL LIME ASSOCIATION
3601 N. Fairfax Drive
Arlington, VA 22201

APPENDIX D

LIST OF ACRONYMS

LIST OF ACRONYMS

ARAR's	Applicable, and Relevant or Appropriate Requirements
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CLP	Contract Laboratory Program (EPA's)
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
ITR	Inorganic Traffic Report
LAP	Laboratory Analytical Protocol
MDHES	Montana Department of Health and Environmental Sciences
NBS	National Bureau of Standards
NPL	National Priorities List
QA/QC	Quality Assurance/Quality Control
QAM	Quality Assurance Manager
QAPP	Quality Assurance Project Plan
RAS	Routine Analytical Services
RI	Remedial Investigation

SARA	Superfund Amendments and Reauthorization Act
SAS	Special Analytical Services
SBC	Silver Bow Creek
SMO	Special Management Office (EPA's)
SOP	Standard Operating Procedure
STARS	Streambank Tailings and Revegetation Study
TSOP	Tailings Study Operations Plan
XRF	Field X-ray Fluorescence Spectometry

APPENDIX E

MATERIAL SAFETY DATA SHEETS

U.S. DEPARTMENT OF LABOR
Occupational Safety and Health Administration

Form Approved
OMB No. 44-R1387

MATERIAL SAFETY DATA SHEET

Required under USDL Safety and Health Regulations for Ship Repairing, Shipbuilding, and Shipbreaking (29 CFR 1915, 1916, 1917)

SECTION I

MANUFACTURER'S NAME: CONTINENTAL LIME INC.	EMERGENCY TELEPHONE NO.: (406)266-5221;442-7094
ADDRESS (Number, Street, City, State, and ZIP Code): P.O. Box 550, Townsend, Montana 59644	
CHEMICAL NAME AND SYNONYMS: Calcium Oxide - Quicklime	TRADE NAME AND SYNONYMS: Quicklime - Hot Lime
CHEMICAL FAMILY: Alkaline	FORMULA: CaO

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, & SOLVENTS	%	TLV (Units)	ALLOYS AND METALLIC COATINGS	%	TLV (Units)
PIGMENTS	0	N/A	BASE METAL	0	N/A
CATALYST	0	N/A	ALLOYS	0	N/A
VEHICLE	0	N/A	METALLIC COATINGS	0	N/A
SOLVENTS	0	N/A	FILLER METAL PLUS COATING OR CORE FLUX	0	N/A
ADDITIVES	0	N/A	OTHERS	0	N/A
OTHERS	0	N/A			

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	TLV (Units)
N/A		

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)	5162	SPECIFIC GRAVITY (H_2O=1)	3.2-3.5
VAPOR PRESSURE (mm Hg.)	N/A	PERCENT, VOLATILE BY VOLUME (%)	Nil
VAPOR DENSITY (AIR=1)	N/A	EVAPORATION RATE (______ =1)	N/A
SOLUBILITY IN WATER Negligible	.05-.14%		
APPEARANCE AND ODOR	White pebbles or granular. Fresh earthy odor.		

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used) N/A	FLAMMABLE LIMITS N/A		Lel	Uel

EXTINGUISHING MEDIA
Non combusitble

SPECIAL FIRE FIGHTING PROCEDURES
When Calcium Oxide comes in contact with water, heat is given off which could ignite paper or wood fibers. Use dry chemical fire extinguishers.

UNUSUAL FIRE AND EXPLOSION HAZARDS
See Above.

(Continued on reverse side)

SECTION V - HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE
5 mg/cu.m.

EFFECTS OF OVEREXPOSURE
Irritation and or chemical burns to eyes, nose and moist skin.

EMERGENCY AND FIRST AID PROCEDURES
Flush eyes immediately with plenty of water followed with Boric Acid solution. Wash affected skin with soap & water, then apply a burn ointment, such as Boric Acid Salve.

SECTION VI - REACTIVITY DATA

STABILITY	UNSTABLE	Yes	CONDITIONS TO AVOID Moisture or chemicals possessing water of crystalization.
	STABLE	Yes	Under dry conditions.

INCOMPATABILITY *(Materials to avoid)* Water

HAZARDOUS DECOMPOSITION PRODUCTS Nil

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID N/A
	WILL NOT OCCUR	X	

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Avoid contact with water.

WASTE DISPOSAL METHOD
In a landfill site that does not contain any combustible material.

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION *(Specify type)* Moldex 2200 Respirators

VENTILATION	LOCAL EXHAUST Yes	SPECIAL --
	MECHANICAL *(General)* Dust collecting system w/a baghouse	OTHER --

PROTECTIVE GLOVES Gauntlet type gloves	EYE PROTECTION Safety Goggles

OTHER PROTECTIVE EQUIPMENT
Long sleeved shirt and pants.

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Quicklime should be stored in a clean dry place to avoid moisture pickup.

OTHER PRECAUTIONS

Avoid contact with the eyes.

Form OSHA-2.
Rev. May 72

MATERIAL SAFETY DATA SHEET

J. T. Baker Chemical Co., 222 Red School Lane, Phillipsburg, N.J. 08865

SECTION I - IDENTIFICATION OF PRODUCT

CHEMICAL NAME Calcium Oxide	FORMULA CaO
SYNONYM OR CROSS REFERENCE Lime	CAS NO: 1305-78-8

SECTION II - HAZARDOUS INGREDIENTS

MATERIAL		NATURE OF HAZARD

SECTION III - PHYSICAL DATA

BOILING POINT	MELTING POINT 2572°C.
VAPOR PRESSURE	SPECIFIC GRAVITY 3.2
VAPOR DENSITY (AIR=1)	PERCENT VOLATILE BY VOLUME (%)
WATER SOLUBILITY Very soluble	EVAPORATION RATE (__________ = 1)

APPEARANCE
White or grayish-white powder

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (method used)	FLAMMABLE LIMITS	Lower	Upper

FIRE EXTINGUISHING MEDIA

SPECIAL FIRE-FIGHTING PROCEDURES Avoid water unless necessary to use on other burning materials, in which case flood with water to absorb heat.

UNUSUAL FIRE AND EXPLOSION HAZARD Not combustible but contact with water or moisture may generate sufficient heat to ignite combustible materials. Also reacts with water to form calcium hydroxide.

SECTION V - HEALTH HAZARD

THRESHOLD LIMIT VALUE
5 mg/M^3

HEALTH HAZARDS Caustic irritant to eyes and respiratory tract. Can cause skin burns in the presence of moisture.

FIRST AID PROCEDURES
In case of contact, flush skin and eyes with plenty of water for at least 15 minutes. Call a physician. If swallowed, if conscious, induce vomiting and call a physician at once.

CHEMICAL NAME

SECTION VI - REACTIVITY DATA

STABILITY			CONDITIONS TO AVOID
	UNSTABLE		
	STABLE	X	Moisture

INCOMPATABILITY (materials to avoid)
Boric oxide and calcium chloride, boron trifluoride, chlorine trifluoride, fluorine, hydrofluoric acid, phosphorus pentoxide, water.

HAZARDOUS DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERIZATION			CONDITIONS TO AVOID
	MAY OCCUR		
	WILL NOT OCCUR	X	

SECTION VII - SPILL AND DISPOSAL PROCEDURES

SPILLS

Carefully sweep up and remove. Flush spill area with water.

DISPOSAL

Material should be disposed of by highly trained individual under strict supervision (professional disposal service). Dispose in accordance with local, state and federal regulations.

SECTION VIII - PROTECTION INFORMATION

RESPIRATORY PROTECTION (specify type)
In dusty atmosphere use Dustfoe 66 or 77 or equivalent

VENTILATION	LOCAL	SPECIAL
	X	
	MECHANICAL (general)	OTHER
	X	

PROTECTIVE GLOVES	EYE PROTECTION
Rubber gloves	Large face shield

OTHER PROTECTIVE EQUIPMENT
Approved working clothes, eyebath.

SECTION IX - HANDLING AND STORAGE PRECAUTIONS

STORAGE & HANDLING

Keep in tightly closed container. Protect against physical damage and store in dry place away from water.

SECTION X - MISCELLANEOUS INFORMATION

Avoid contact with eyes, skin, clothing. Wash thoroughly after handling.

Date issued: 8/3/83 Revision: ____ Approved by R. M. Mitchell
Manager, Quality Assurance

MATERIAL SAFETY DATA SHEET

J. T. Baker Chemical Co., 222 Red School Lane, Phillipsburg, N.J. 08865

CHEMICAL NAME

SECTION I - IDENTIFICATION OF PRODUCT

CHEMICAL NAME	FORMULA
Calcium Hydroxide	$Ca(OH)_2$
SYNONYM OR CROSS REFERENCE: Lime	CAS NO: 1305-62-0

SECTION II - HAZARDOUS INGREDIENTS

MATERIAL		NATURE OF HAZARD

SECTION III - PHYSICAL DATA

BOILING POINT	MELTING POINT
VAPOR PRESSURE	SPECIFIC GRAVITY 2.3
VAPOR DENSITY (AIR=1)	PERCENT VOLATILE BY VOLUME (%)
WATER SOLUBILITY Almost insoluble	EVAPORATION RATE (________ = 1)

APPEARANCE
Colorless crystals, granules or powder

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (method used)	FLAMMABLE LIMITS	Lower	Upper

FIRE EXTINGUISHING MEDIA

SPECIAL FIRE-FIGHTING PROCEDURES

UNUSUAL FIRE AND EXPLOSION HAZARD

SECTION V - HEALTH HAZARD

THRESHOLD LIMIT VALUE
15 mg/M^3 nuisance dust

HEALTH HAZARDS
Causes irritation to skin and eyes.

FIRST AID PROCEDURES In case of contact, immediately flush eyes or skin with plenty of water for atleast 15 minutes. Call a physician. If swallowed, if conscious, give large amounts of water, milk or citric juice. Call a physician. If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.

SECTION VI – REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	

INCOMPATABILITY (materials to avoid)

Acids

HAZARDOUS DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	

SECTION VII – SPILL AND DISPOSAL PROCEDURES

SPILLS

Carefully sweep up and place in large bucket. Dilute with water and neutralize with 6M-HCl. Drain into sewer with sufficient water providing local environmental regulations permit.

DISPOSAL

Put into large vessel containing water. Neutralize with HCl. Discharge into sewer with sufficient water providing local environmental regulations permit.

SECTION VIII – PROTECTION INFORMATION

RESPIRATORY PROTECTION (specify type) In dusty atmosphere, simple dust respirator will be used. Dustfoe 66 or 77 or equivalent.

VENTILATION	LOCAL	SPECIAL
	X	
	MECHANICAL (general)	OTHER
	X	

PROTECTIVE GLOVES	EYE PROTECTION
Rubber gloves	Safety glasses or goggles

OTHER PROTECTIVE EQUIPMENT

Approved working clothes

SECTION IX – HANDLING AND STORAGE PRECAUTIONS

STORAGE & HANDLING

Keep in tightly closed container.

SECTION X – MISCELLANEOUS INFORMATION

Avoid breathing dust. Avoid contact with eyes, skin, clothing.
Wash thoroughly after handling.

Date issued:________ Revision:________ Approved by R. M. Mitchell

Manager, Quality Assurance

EM SCIENCE
111 Woodcrest Road, P.O. Box 5018, Cherry Hill, N.J. 08034-0395, Phone (609) 354-9200

MATERIAL SAFETY DATA SHEET

Essentially Similar to U.S. Department of Labor Form OSHA-20

SECTION 1 NAME & PRODUCT

Chemical Name: Ferric Sulfate	Catalog Number: FX0235, FX0237
Trade Name & Synonyms: Ferric Persulfate CAS #10028-22-5	Chemical Family: Metal Salt
Formula: $Fe_2(SO_4)_3 \cdot xH_2O$	Formula Weight: $399.90 + xH_2O$

SECTION 2 PHYSICAL DATA

Boiling Point, 760 mm Hg (°C)	N/A	Specific Gravity (H_2O = 1)	3.1
Melting Point (°C)	N/A	Solubility in H_2O, % by wt. at 20°C	Soluble
Vapor Pressure at 20°C	N/A	Appearance and Odor	grayish white to yellow solid
Vapor Density (air = 1)	N/A		
Percent Volatiles by Volume	N/A	Evaporation Rate (Butyl Acetate = 1)	N/A

SECTION 3 FIRE AND EXPLOSION HAZARD DATA

Flash Point (test method)	Nonflammable	Flammable Limits	Lel N/A	Uel	N/A

Extinguishing Media: Any suitable for other material involved

Special Hazards and Procedures: None

Unusual Fire and Explosion Hazards: None

SECTION 4 REACTIVITY DATA

Stable	X	Conditions to Avoid: Moisture (material is hygroscopic)
Unstable		

Materials to Avoid

( ) Water (XX) Mineral Acids ( ) Bases ( ) Corrosives ( ) Oxidizers

( ) Other (specify)

Hazardous Decomposition Products: S, SO_x

SECTION 5 SPILL OR LEAK PROCEDURES AND DISPOSAL

Steps to be Taken in Case Material is Released or Spilled: Sweep up & containerize for proper disposal

Waste Disposal Method: To be performed in compliance with all current local, state and federal regulations

FX0235, 0237

SECTION 6 HEALTH HAZARD DATA

Threshold Limit Value

None Established

Effects of Overexposure

Irritating to eyes, skin and mucous membranes

Prolonged exposure may be injurious to health

First Aid Procedures

Eyes: flush thoroughly with water; get immediate medical attention
Skin: wash with soap/water; get medical attention for persistent dermatitis
Inhalation: remove to fresh air; get medical attention
Ingestion: get medical attention

SECTION 7 SPECIAL PROTECTION INFORMATION

Ventilation, Respiratory Protection, Protective Clothing, Eye Protection

Provide adequate general mechanical and local exhaust ventilation
Protect eyes and skin with safety goggles and gloves
Do not breathe dust or vapors
Do not get in eyes, on skin, or on clothing

SECTION 8 SPECIAL HANDLING AND STORING PRECAUTIONS

Keep container closed and protected from light
Store in a cool, dry, well-ventilated area
Use only clean, dry utensils in handling
Wash thoroughly after handling

DOT - ORM-E

SECTION 9 HAZARDOUS INGREDIENTS

(refer to section 3 through 8)

SECTION 10 OTHER INFORMATION

EMERGENCY PHONE NUMBER (609) 423-6300

AUTHORIZED SIGNATURE ____________

DATE ISSUED: 6/82

DATE REVISED: 2/84

EM0014TA

J.T.Baker

MATERIAL SAFETY DATA SHEET

J. T. Baker Chemical Co., 222 Red School Lane, Phillipsburg, N.J. 08865

✓

SECTION I - IDENTIFICATION OF PRODUCT

CHEMICAL NAME Ferrous Sulfate, 7-Hydrate	FORMULA $FeSO_4 \cdot 7H_2O$
SYNONYM OR CROSS REFERENCE Copperas	CAS NO: 7720-78-7 ✓

SECTION II - HAZARDOUS INGREDIENTS

MATERIAL		NATURE OF HAZARD

SECTION III - PHYSICAL DATA

BOILING POINT	MELTING POINT Loses $3H_2O$ at 58°C.
VAPOR PRESSURE	SPECIFIC GRAVITY 1.89
VAPOR DENSITY (AIR=1)	PERCENT VOLATILE BY VOLUME (%)
WATER SOLUBILITY Soluble	EVAPORATION RATE (__________ = 1)

APPEARANCE
Blue-green, odorless crystals or granules

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (method used)	FLAMMABLE LIMITS	Lower	Upper

FIRE EXTINGUISHING MEDIA

SPECIAL FIRE-FIGHTING PROCEDURES

UNUSUAL FIRE AND EXPLOSION HAZARD

SECTION V - HEALTH HAZARD

THRESHOLD LIMIT VALUE
Unknown

HEALTH HAZARDS
Harmful if swallowed. LD_{50}(rat) = 0.5-5g/kg

FIRST AID PROCEDURES If swallowed, give milk at once and then induce vomiting. Gastric lavage with water. Get medical attention.

CHEMICAL NAME

SECTION VI - REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	

INCOMPATABILITY (materials to avoid)
Alkalies, soluble carbonates, gold and silver salts, lead acetate, lime water

HAZARDOUS DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	

SECTION VII - SPILL AND DISPOSAL PROCEDURES

SPILLS

Sweep up and remove.

DISPOSAL

Dispose in landfill providing local environmental regulations permit. Prevent pollution of water intake areas.

SECTION VIII - PROTECTION INFORMATION

RESPIRATORY PROTECTION (specify type)
Dust mask may be appropriate if dust is present

VENTILATION	LOCAL	SPECIAL
	MECHANICAL (general)	OTHER

PROTECTIVE GLOVES	EYE PROTECTION Safety glasses

OTHER PROTECTIVE EQUIPMENT

SECTION IX - HANDLING AND STORAGE PRECAUTIONS

STORAGE & HANDLING
Store in container at room temperature that
Store in tightly-closed container at room temperature.

SECTION X - MISCELLANEOUS INFORMATION

See Merck Index, 9th ed., 1976, item 3982 for additional information.

Date issued: 8/84 Revision: ______ Approved by R. M. Mitchell
Manager, Quality Assurance

MATERIAL SAFETY DATA SHEET

J. T. Baker Chemical Co., 222 Red School Lane, Phillipsburg, N.J. 08865

SECTION I - IDENTIFICATION OF PRODUCT

CHEMICAL NAME	FORMULA
Calcium Carbonate	$CaCO_3$
SYNONYM OR CROSS REFERENCE	CAS NO: 471-34-1

SECTION II - HAZARDOUS INGREDIENTS

MATERIAL		NATURE OF HAZARD

SECTION III - PHYSICAL DATA

BOILING POINT	MELTING POINT
VAPOR PRESSURE	SPECIFIC GRAVITY 2.7
VAPOR DENSITY (AIR=1)	PERCENT VOLATILE BY VOLUME (%)
WATER SOLUBILITY 0.001 g/100 ml	EVAPORATION RATE (________ = 1)

APPEARANCE
Fine, white powder; odorless

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (method used)	FLAMMABLE LIMITS	Lower	Upper

FIRE EXTINGUISHING MEDIA Any media suitable for the supporting fire.

SPECIAL FIRE-FIGHTING PROCEDURES
Wear dust mask

UNUSUAL FIRE AND EXPLOSION HAZARD

SECTION V - HEALTH HAZARD

THRESHOLD LIMIT VALUE

HEALTH HAZARDS

FIRST AID PROCEDURES

CHEMICAL NAME

SECTION VI - REACTIVITY DATA

STABILITY	UNSTABLE		CONDITIONS TO AVOID
	STABLE	X	

INCOMPATABILITY (materials to avoid)

Acids

HAZARDOUS DECOMPOSITION PRODUCTS

Calcium oxide when heated to decomposition.

HAZARDOUS POLYMERIZATION	MAY OCCUR		CONDITIONS TO AVOID
	WILL NOT OCCUR	X	

SECTION VII - SPILL AND DISPOSAL PROCEDURES

SPILLS

Sweep up and dissolve in solution excess of acid.

DISPOSAL

Flush to sewer with excess water or dispose in landfill providing local environmental regulations permit.

SECTION VIII - PROTECTION INFORMATION

RESPIRATORY PROTECTION (specify type)

Dust mask

VENTILATION	LOCAL	SPECIAL
	MECHANICAL (general) X	OTHER

PROTECTIVE GLOVES	EYE PROTECTION
	Safety goggles

OTHER PROTECTIVE EQUIPMENT

SECTION IX - HANDLING AND STORAGE PRECAUTIONS

STORAGE & HANDLING

Store in a cool, dry place.

SECTION X - MISCELLANEOUS INFORMATION

Date issued: 8/3/83 Revision: Approved by R. M. Mitchell

Manager, Quality Assurance